PROCESS TIME REFINEMENT FOR REUSABLE LAUNCH VEHICLE REGENERATION MODELING

THESIS

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Abstract

To sustain operational effectiveness, the Air Force has invested in the research and development of space-based technologies. Certain ongoing spacelift research efforts are focused on developing operationally responsive Reusable Military Launch Vehicles (RMLV) capable of launching payloads into orbit within hours of a tasking notification. Previous Air Force Research Laboratory-sponsored AFIT studies have resulted in the development of the MILEPOST discrete-event simulation model. This model has enabled the ability to analyze the impacts to responsiveness and manpower requirements given different RMLV design alternatives. The focus of this thesis is to improve the fidelity of the MILEPOST model by developing parametric models of simulation process times in terms of certain influential factors which affect maintenance task times.

Based on MILEPOST process modules, the research developed a Work Unit Code (WUC) structure, providing the means to document key maintenance tasks which are required during the regeneration of the vehicle. Additionally, the research determined that significant parametric relationships exist between task times and certain influential vehicle design and human factors. Incorporated into the MILEPOST model, the identified prediction expressions provide a more precise evaluation of RMLV design alternatives.

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To mother, father, wife and children

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I. Introduction

Background

As the United States military moves further into the 21st century, the control and exploitation of space becomes more and more critical to military operations. Due to increasing threats to our National Defense, the United States' top military leaders have recognized the significance of developing strong space-based defense capabilities. Since the end of the Cold War, the focus of the United States' warfighting capability has shifted from airpower, to aerospace, and now today, air and space power (Brown, 2004). This shift in strategy at the national defense level has had a direct effect on the strategic focus of the Air Force. In order to meet its objectives, the Air force must develop future space systems which will be responsive as well as efficient. Responsive spacelift is thought of as the capability to launch space vehicles at a moment's notice, i.e., not taking weeks or even months as it currently does (Steigelmeier, 2006). Therefore, it is imperative for the Department of Defense to develop a robust and responsive spacelift capability.

In the Global War on Terrorism, the United States military is fighting a new enemy, thus the style of warfare has changed. Many of the capabilities and successes

attained thus far in Operation Iraqi Freedom (OIF) are a direct result of space assets. The troops on the ground rely heavily on the use of satellites for global positioning systems (GPS) which enable precise navigation, precision-guided munitions; global communications; and intelligence, surveillance, and reconnaissance (Brown 2004).

According to Air Force Doctrine Document 1 (Air Force, AFDD-1, 2003), during any military operation, space superiority is necessary to secure the freedom of military actions in all battlefield environments; superiority in space allows for the freedom to attack as well as defending against an attack (Air Force, AFDD-1, 2003). Based on this doctrine the Air Force's space mission is based on the following four purposes:

1) Deploying space systems to fulfill new requirements for satellite service.
2) Sustaining existing space systems whose individual satellites are nearing the end of their useful life, predicted to fail, or have failed.
3) Augmenting existing space systems with redundant or additional capability to enhance space system performance or increase system survivability should national security dictate.
4) Servicing and maintaining existing or newly deployed space systems.

Furthermore, the implementation of the Air Force's space priorities is obtained through the approaches of launching-on-schedule, and launching-on-demand (Air Force, AFDD-1, 2003).

Problem Statement

For the past several years, the Air Force Research Lab has sponsored several AFIT Theses and research projects on Reusable Military Launch Vehicles (RMLV) modeling. The results of the previous graduate researchers' efforts have provided a

significant amount of supporting data that support the Air Force's further consideration of reusable spacelift. Due to the fact that this "spacecraft" does not currently exist, previous attempts to gather accurate RMLV concept data have proven difficult. To overcome the lack of existing systems information, computer simulation has been employed to produce data as if the RMLV existed today. During the creation of these models, a significant amount of the input data used to portray actual process times was determined to be the "best guess" of one or more subject-matter experts. As the Air Force moves closer to creating such a space vehicle, a more accurate assessment of the model data is required.

Research Objective

"In order to increase maintainability, in some manner the repair time must be reduced. There are several key concepts that should be followed as part of any design activity that supports this reduction." (Ebeling, 2005). Significant benefits can be realized if the time it takes to repair an item is reduced.

The ultimate goal of this research is to improve the fidelity of the RMLV simulation model previously developed, by tailoring process times to vehicle design variables. Improving the accuracy and precision of the simulation model adds validity to the RMLV concept, thus providing critical information for decision making. This will ensure the leaders in decision-making positions are basing their decisions on accurate information thus avoiding the possible over-expenditure of critical budget dollars.

Research Focus

The combined effort of the authors of the previously identified theses has resulted in the construction of a simulation model which simulates post-landing, ground maintenance and prelaunch operations of a RMLV. This model has been titled as the

MILEPOST Model for simulating RMLV activities. In the process of model development, the authors created 176 individual processes associated with the ground support operations of a future RMLV. These processes have been included in their MILEPOST model.

The focus of this research is to identify the most significant processes and conduct an analysis to determine possible parametric relationships to maintenance times to determine how these process times are affected by key design parameters, thus improving the fidelity of previously determined turn-around times between future RMLV launches.

Since a lot of uncertainty exists with the study of a not-yet-produced conceptual program, current research must be based on tangible data in order to exhibit credibility. It was for this reason that the models previously built were based on a variety of systems, including NASA's space shuttle missions and the Air Force's B-2 bomber operations (Steigelmeier, 2006). Additionally, prior modeling efforts included data collected from F-16 aircraft, Atlas V, Delta IV, Zenit, and Intercontinental Ballistic Missile (ICBM) rockets as well. Previously, many subject matter experts in these areas were contacted and interviewed to determine estimated process times which were included in the MILEPOST model.

As with previous research in this area, the focus of this study will be limited to the evaluation of vehicles (Shuttle, Rockets, or Aircraft) which currently exist today. Although needed to establish a baseline model, the RMLV operations of the future may be better correlated to additional existing aircraft in addition to the space shuttle or B-2 bomber. Therefore, the collection of accurate data from four aircraft types existing today

(B-2, C-5, KC-135, and F-16) is paramount in determining more robust maintenance process times for use in the RMLV modeling efforts of the future.

Research Questions

In order to improve the fidelity of the previous research in the area of RMLVs, the following research question is addressed:

> What parametric relationships exist between MILEPOST regeneration process activity times and certain vehicle design and influential human factors?

To guide this research effort, the following investigative questions have been formulated:

1. What main vehicle design and human factors affect the overall time to accomplish maintenance repair actions?

2. Can a notional Air Force Maintenance Work Unit Code table be created using the tasks and processes identified in MILEPOST?

3. Can a notional MILEPOST Work Unit Code Table be seamlessly incorporated into existing Air Force maintenance information systems?

4. What parametric relationships can be determined between maintenance repair factors and the overall time to complete certain maintenance actions be determined?

All of these questions provide opportunities for further research within the RMLV arena. By focusing on the key processes and identifying what variables affect the processes, significant data can be attained thus increasing the DOD support for RMLV programs of the future. This research has become more important as technological advances in the areas of global positioning satellites and improvements in satellite imagery have occurred.

Assumptions/Limitations

The biggest limitation to this research is in the area of existing data and information. Within the Department of Defense, RMLVs are still in the conceptual stages of development. As a concept vehicle, any significant analyses must rely heavily on data gathered from existing aircraft, which may or may not accurately represent any functional system engineered and fitted on an actual RMLV, if funded or produced. This research was limited to the analysis of aircraft data only; no space systems data was used. Additionally, due to the small number of data points used in the creation of regression models, the normally required testing of residuals was impossible to accomplish. Moreover studies involving technologies which have yet to be produced tend to rely on a significant number of assumptions and limitations as the complexities and technological details are constantly changing.

Implications

The future of Air Force space operations is dependent upon accurate and detailed research of today. In order to maintain superiority over our enemies it is imperative for the DOD to continue to look out to new horizons in technology to maintain its edge. One area which is currently being pursued is the RMLV program. The purpose of this research is to review previous published research and conduct in-depth analysis to add fidelity and validity to the ongoing efforts within the RMLV program.

Summary and Preview

This chapter provided a justification of the need for the United States to continue to develop space-based technologies and identified that those technologies need to be responsive. The objective of this research was presented and the research focus was

discussed along with the research and investigative questions. Chapter II provides an overview of previous RMLV research studies and maintenance documentation history as well as an introduction to parametric and human factors analyses. Chapter III will describe the methodologies used in this research. Chapter IV includes the presentation of a notional Work Unit Code table and parametric models developed for this thesis. Chapter V presents the research conclusions and identifies future areas for additional research.

II. Literature Review

Introduction

This chapter will provide a more in-depth explanation of the key aspects of the previously stated focus of this research. The justification of the research will be further supported with the presentation of historical information. Additionally, key terms and concepts will be defined and scoped to this topic, and methodological background data will be discussed. The supporting literature of this research is presented in this chapter as follows:

1. U.S. Spacelift Objectives
2. History of Reusable Launch Vehicles
3. Brief description of MILEPOST model
4. Previous RLV/RMLV Development
5. Historical Maintenance Documentation
6. Modern Maintenance Documentation
7. Launch Vehicle Parametric Analyses
8. Human Factors Affecting Maintenance

Guiding this review was the intention of providing an understandable background providing direction for the research of each investigative question, culminating in the identification of the key parameters which affect the processes within the ARENA MILEPOST model.

Spacelift Objectives

On August 31, 2006, the President of the United States authorized a new national space policy. This policy forms the guiding principles and provides national policies and objectives that govern U.S. space activities (President, 2006). Since the 1960s, the United States has been the world's "super-power" in the arena of space technology and exploration. This leading focus has resulted in many improvements to the lifestyles of the American people such as enhanced security and protection of people and their environment and tremendous increases in the speed of information, thus resulting in a solid economy (President, 2006). Today, there are many threats to our National Security, specifically to our space assets. As a result, the President made it a point to include the following as one of his key principles in his space policy:

> "The United States considers space capabilities -- including the ground and space segments and supporting links -- vital to its national interests. Consistent with this policy, the United States will: preserve its rights, capabilities, and freedom of action in space; dissuade or deter others from either impeding those rights or developing capabilities intended to do so; take those actions necessary to protect its space capabilities; respond to interference; and deny, if necessary, adversaries the use of space capabilities hostile to U.S. national interests." (President, 2006)

The protection of our national assets and way of life has always been a priority for our country's leaders. Invariably, the United States has been faced with foreign states that have demonstrated capabilities that threaten U.S. assets. One such example of this is China's successful test of an anti-satellite weapon. On January 17, 2007, China demonstrated its advancement in space technologies by successfully launching a missile into Earth's orbit and destroying one of its own satellites (Covault, 2007). In the 2006 Office of the Secretary of Defense's (OSD) Annual Report to Congress, OSD had foreshadowed this eventuality when they identified China's capability to strike space

targets with precision (OSD, 2006). Now carried out, this demonstration provided a warning to U.S. leaders to take a closer look at its own space program. Additionally, by the end of 2007, Russia, India, United Kingdom, and Japan have made great advancements within their respective space programs (Henry, 2007).

The advancement of these foreign states' space capabilities comes at a pivotal point in the history of the United States space program. According to National Aeronautics and Space Administration's (NASA) 2006 Strategic Plan, the Space Shuttle (program) will be retired no later than 2010 (NASA, 2006). This will result in a void in space capability that has only been provided by the space shuttle. Currently, the Space Shuttle is the only reusable orbital launch vehicle in the world (Crocker 2004). Thus realizing this decline in capability, strategic leaders of the Air Force have been proactive in developing concepts for the future designs of a RMLV to be used to support military operations while implementing the National Space Policy.

The Air Force Transformation Flight Plan of 2004 includes Rapid Air and Space Response as one of its six long-term challenges for future investment (U.S. Air Force, 2004). The development of a RMLV will provide the Air Force with a capability that will ensure space dominance for the future and fulfills the President's direction to all DOD departments and agencies of achieving improved capabilities through technological advances resulting in new discoveries in space science (President, 2006). Therefore as the dependence of space capabilities by our national security objectives increases, the Air Force will be postured for success.

History of Reusable Launch Vehicles

The reusable launch vehicle (RLV) concept has been around for many years. In fact, during NASA's Apollo mission timeframe it was noted that certain economies could be gained by developing reusable space capabilities. During the early 1970s, NASA engineers developed and tested several RLV options. The only of these which made it to fully successful operations was the Space Shuttle. Unfortunately, the lower costs thought to be associated with a reusable launch system have not been realized during the Shuttle missions (Raskey, et al, 2006).

Through the years, there have been many factors which have had a negative affect on the economics of the shuttle program, but the factor which has had the most impact is the reduced flight rate. In order for the RLVs undergoing testing and development today to realize true cost effectiveness and positive returns on investment, their flight rates must be large (Raskey, et al, 2006). The ability to achieve lower production costs of an RLV is due to the fact that the costs can be amortized over the lifetime of the system due to the multiple flights launched per vehicle (Herrmann and Akin, 2005). To achieve increased flight rates, a combination of technology and market strategies are necessary. Modern maintenance technologies are needed for quick turnaround times and private industry and open market involvement must be present in order to increase demand (Raskey, et al, 2006).

In 2002, NASA began looking for serious alternatives to its Space Shuttle program. At this time, NASA formed a Next Generation Launch Technology program. The objectives of this program were to meet national space objectives by creating safe,

affordable, reliable, and responsive space systems. This resulted in a focus on Reusable Launch Vehicle (RLV) technology (Crocker 2004).

In 2003, The US Air Force Space Command (AFSPC) completed an operationally responsive space (ORS) concept analysis of alternatives (Brown, 2004). The primary purpose of this concept was to accurately identify how cost effective and responsive space systems are (Brown, 2004). Militarily, AFSPC concluded that having an ORS capability "can provide significant military utility at the campaign level" (Brown, 2004).

From the conclusions of their study, AFSPC began looking into the viability of designing and creating new space systems to meet their previously established goals. Unfortunately, the process of developing such systems takes many years and significant levels of critical budget dollars to complete (Brown, 2006). Realizing the urgent need for strong space capabilities to support future threats, the U.S. Space Transportation Policy was published on 6 January 2005. This policy reaffirms the critical need for space assets and established primary goals of responsiveness, reliability, and affordability (Brown, 2006).

More recently, AFSPC and the Air Force Research Laboratory (AFRL) have conducted initial space system-acquisition studies which have included design concepts of a RLV (Brown, 2006). Considering the fact that the Space Shuttle has never met many of its original objectives (McCleskey, 2005), and given the goals of the future space program, the researchers' analyses identified a hybrid launch vehicle (HLV) is the best alternative to meet previously established goals (Brown, 2006).

Applying the lessons-learned from past space operations and taking into consideration future objectives, AFRL has developed its concept of a RMLV. The

foresight of this concept has resulted in the development of computer simulation models of conceptual RMLVs. (Brown, 2006). In 2004, AFRL's Brendan Rooney and Alicia Hartong used simulation to identify the need for the Air Force to develop a RMLV. Investigating the overall responsiveness of a RMLV, Rooney and Hartong investigated historical space vehicles, focusing on maintenance times. This enabled them to identify the systems with greatest maintenance problems and focused their research on identifying probability distributions which were used to simulate RMLV times in their model (Rooney and Hartong, 2004). In determining theoretical man-hours needed to maintain a RMLV, only historical Space Shuttle data were used.

Brief Description of MILEPOST

Although the conceptual RMLV is similar to the Space shuttle, the overall design, operational capability, and maintenance should be much simpler than the shuttle, given the unmanned mission aspect (Pope, 2006). Furthermore, the USAF's primary focus is on a timely inter-launch turnaround time capability. Through 2005, NASA has only been able to launch the shuttle at most seven to eight times per year (McCleskey, 2005). Further analysis reveals that the shortest time between successive launches for any one individual shuttle was 50 days (NASA, 2008). This frequency of launch is not acceptable for the future vision of the Air Force. Therefore, in the simulation models published by Air Force Institute of Technology's graduate students, other air and space vehicle data to include the Atlas V, Delta IV, F-16, and B-2 were collected and utilized. The overall combined effort of the authors of the previously identified theses has resulted in the construction of an ARENA Simulation model, MILEPOST, which simulates the maintenance operations of a RMLV (Martindale, Pope, Steigelmeier, 2006).

The current MILEPOST model is made up of three individual Arena sub-models comprising of 176 individual maintenance processes which are linked together providing an estimated timeline for all theoretical RMLV activities occurring from post-landing through re-launch. The first sub-model encompasses post-landing operations. The process times in this portion of the model were based primarily on F-16 post-landing recovery operations (Martindale, 2006). The second main sub-model simulates RMLV ground maintenance operations which occur between launch cycles. During this portion the major vehicle components undergo complete maintenance inspection and/or repair. These components are similar to existing aircraft and ICBM fuel, hydraulic, propulsion, electrical, environmental, and structural systems (Pope, 2006). Additionally, the unique maintenance requirements (example: Thermal Protection System) of a space vehicle are conducted (Pope, 2006). This portion of the model is based primarily on shuttle and B-2 data due to the greater similarity of the RMLV concept to Shuttle inter-launch maintenance activities than fighter aircraft (Pope, 2006). The final main sub-model involves pre-launch operations. It is at this portion that the highest degree of design variability occurs during the simulation. Additionally, to improve the fidelity of the model, research was conducted to determine the logistics manpower requirements needed to accomplish RMLV turnaround processes (Michalski, 2007).

RLV/RMLV Development

Early Testing of Reusable Launch Technology

From the origins of spaceflight into the late 1990s, many within the U.S. space industry felt that reusable launch technology would be critical to the future of space exploration. In response to this theory, McDonnell Douglas Aerospace (MDA)

conducted a series of launch tests to determine the feasibility of creating reusable launch vehicle technology. The results of these tests proved that reusable rocket technology is available as well as attainable (Rampino, 1996). The successful demonstrations of MDA's reusable launch vehicle program stimulated the conceptual development of RMLVs. Additionally, these tests proved that, if implemented, reusable launch technologies could reduce costs associated with launching payloads into space while providing increased capability of recovery and return of space assets back to Earth (Rampino, 1996). Moreover, the need was identified at this time for the DOD to explore implementing a RMLV program that would benefit the military as well as provide capabilities and incentives for commercial RLV development as well.

Current Launch Vehicle Developments

Since that time, the space industry has gained a significant amount of attention, drawing the focus of many government and commercial agencies. The early successes of reusable launch technology tests spurred further consideration and investment in developing new technologies. As a result, the DOD and several commercial developers have realized the potential for attaining sufficient return on investment and have implemented programs to develop reusable launch vehicle. Currently, in addition to the DOD development efforts, there are approximately eleven commercial developers actively pursuing the goal of creating viable reusable space vehicles (FAA, 2007). Table 1 identifies the current commercial RLVs. As more and more development efforts prove to be successful, the Air Force continues to make technological improvements in designing RMLV development alternatives.

Table 1: Commercial Reusable Launch Vehicles Development Efforts (FAA, 2007)

RLV NAME	Commercial Developer	First Launch
Quad	Armadillo Aerospace	20-Oct-06
New Shepard	Blue Origin	Projected: NLT 2010
Sea Star	Interorbital Systems	Projected: NLT 2008
Neptune	Interorbital Systems	Projected: NLT 2009
XA 1.0	Masten Space Systems	Projected: NLT 2008
K-1	Rocketplane Kistler	Projected: Late 2008
Rocketplane XP	Rocketplane Kistler	Projected: Late 2008
SpaceShipTwo	Scaled Composites, LLC/Virgin Galactic	Projected: NLT 2008
Dream Chaser	SpaceDev	Projected: NLT 2009
Falcon 1	Space Exploration Technologies Corporation	24-Mar-06
Falcon 9	Space Exploration Technologies Corporation	Projected: 1st Qtr 2008
Altairis	Sprague Astronautics	Projected: Mid 2008
Michelle-B	TGV Rockets, Inc.	TBD
Xerus	XCOR Aerospace	TBD

Maintenance Documentation History

From the early days of powered flight, it was evident that properly maintaining and keeping accurate records of aircraft systems was critical to the reliability and overall cost-effectiveness of the system. For example, the Wright brothers designed, flew, and repaired their own aircraft (Pope, 2006). As improvements and changes to their designs were made on a regular basis, the Wrights were meticulous in documenting any repair actions. As more and more aircraft were developed, it remained the responsibility of the pilot to be familiar with the entire aircraft system, making and documenting repairs as necessary (Pope, 2006).

In the 1920s, many aircraft were in operation and technology was advancing at an astounding rate. Military aircraft maintenance efforts improved with the introduction of

in-depth aircraft maintenance documentation efforts. The record keeping at this time enabled the determination of overall aircraft condition, acquisition details, and daily aircraft reports (George, et al., 2004).

The 1930s saw the number of aircraft in the Army Air Service grow to approximately 2,000. Prior to World War II, a Material Division was formed in order to establish standard policies and procedures over all maintenance actions which took place within the entire United States (George, et al., 2004). This single authority over maintenance was adopted by the Air Force as it became its own service. In 1956, Air Force Manual, 66-1, Maintenance Management, was published to set Air Force standards, goals, and objectives for maintenance. Additionally, the establishment of standardized maintenance data collection procedures was a key initiative of the new guidance (George, et al., 2004).

The availability of maintenance data has allowed the Air Force to conduct studies over the years in attempts to improve operations and reduce costs. In 2006, it was reported that the Air Force's maintenance costs were growing at twice the rate of inflation (Painter, et al., 2006). Many studies have been conducted to explain the reasons for cost escalations and determine solutions to reduce maintenance related costs. During these studies, the primary data analyzed is derived from historical maintenance sources. As the fleet of aircraft in the Air Force inventory continues to age, maintenance data can be used in analyses to identify significant parametric relationships in creating models which may pinpoint areas for improvement throughout the entire life cycle of the weapon system (Painter, et al., 2006).

According to Air Force Instruction 21-101, "Aircraft and equipment readiness is the maintenance mission." Furthermore, it is through maintenance technicians' actions of inspecting, repairing, overhauling, modifying, preserving, refurbishing, troubleshooting, testing, and analyzing that quality of maintenance is achieved. Enabling this quality of maintenance is the integrity and skill of each and every maintenance technician in their use of current and serviceable technical orders, checklists, guides and Work Unit Code (WUC) manuals (Air Force, AFI 21-101, 2006).

Modern Maintenance Documentation

Maintaining a fleet of over 6,000 aircraft is an arduous task for the Air Force (Air Force, AFSAC, 2008). It is through the use of standardized reporting and documentation efforts that the high quality of aircraft maintenance is achieved. One example of how maintenance is standardized in the Air Force is through the use of WUC manuals.

As specified by the Air Force data collection system, "each maintenance action performed on Air Force equipment must be fully and accurately documented" (Air Force, MIL-PRF-38769D, 1996). Due to the vast amount of data produced on a day-to-day basis, recording and storing the details of maintenance requires the use of highly capable information systems. These information systems require data be inputted in standardized form. This is accomplished through the use of the following codes: type of maintenance, action taken, when discovered, and type of malfunction (Air Force, MIL-PRF-38769D, 1996). Furthermore, the five-character WUCs have been developed for each weapon system, identifying the system, subsystem, or component on which maintenance was performed or is scheduled to be accomplished. Primarily, WUCs are developed to identify the specific part of the system on which work has been accomplished, thus

providing relationships of the part within a major assembly, subassembly, etc. (Air Force, MIL-PRF-38769D, 1996).

As part of the acquisition process, Air Force Material Command's (AFMC) equipment managers are responsible for creating, assigning and publishing WUCs for every new weapon system (Air Force, T. O. 00-20-2, 2007). These WUCs set the foundation for collecting, storing, and retrieving maintenance data. The data are used within the Air Force's equipment management, maintenance management, and reliability and maintainability improvement programs (Air Force, T. O. 00-20-2, 2007). The accuracy of the data reported is critical to any subsequent analysis which may determine opportunities for improved reliability, maintainability, and availability of Air Force aircraft. Supporting the goal of standardizing maintenance data documentation, the information stored in the Air Force's Reliability and Maintainability Information System (REMIS) takes precedence over all other data sources (Air Force, T. O. 00-20-2, 2007).

According to Air Force Computer Systems Manual 25-524, as of 1985, REMIS became the "central common source of all unclassified maintenance and selected supply information for USAF weapons systems." Furthermore, REMIS is known as the primary worldwide data system used by maintenance managers. As REMIS is able to integrate several existing maintenance systems into one central database, the data found in its tables are routinely used to evaluate current weapons systems on a real-time basis allowing for more informed system sustainment decisions (Air Force, AFCSM 25-524, 2002).

The most common existing maintenance system in use throughout the Air Force is the Core Automated Maintenance System (CAMS). When using CAMS to input job

completion reports, maintenance technicians are required to use WUCs as the main identifier to the action. The accuracy of the data introduced into the system is critical in determining the overall status of a certain weapons system. For example, CAMS is used within Air Mobility Command (AMC) to manage and document maintenance activities and processes. AMC utilizes an exclusive version of CAMS, CAMS for Mobility (G081) Maintenance Management Information System to manage and document maintenance activities and processes. As part of the G081 user's training, it is emphasized that by inputting accurate data, one can have a tremendous impact on the success of tacticians' plans and logisticians' support (AMC, 2008). Furthermore, Air Force Space Command (AFSPC) guidance identifies that space-based maintenance data must interface with CAMS or REMIS. By doing so, AFSPC is able to "enhance system design and increase the readiness and sustainability of space systems by improving the availability, accuracy, and flow of essential hardware, equipment, and infrastructure maintenance information" (AFSPCI 21-10801, 1996).

Launch Vehicle Parametric Analyses

As the Air Force pursues the development of future space systems to be responsive as well as efficient, a review of significant previous studies is in order. Since responsive spacelift is understood as the capability to launch space vehicles at a moment's notice, an investigation to determine which key factors inhibit expeditiously launched consecutive missions is necessary (Steigelmeier, 2006). Considered the only reusable orbital launch vehicle in the world, the Space Shuttle has had numerous studies focused on determining the causes of its sluggish turn-around times (Crocker 2004). One key factor which has been identified is the underestimation of required maintenance times

between launches (McCleskey, 2005). Thus, in order to attain the goals of responsiveness, modern maintenance technologies are needed for quick turnaround times (Raskey, et al, 2006).

Initial studies which were conducted to define conceptual launch vehicles operations focused on employing discrete event simulation techniques (Morris, et al., 1995). While these models did provide some insight, they were primarily based on assumed parametric values, normally aggregated at a high level (Morris, et al., 1995). In order to improve model fidelity, additional research has been conducted. The purpose of these research efforts was to identify key relationships of design and maintenance concept decisions during vehicle design (Morris, et al., 1995).

Several quantitative studies have been conducted in an attempt to identify and explain what key factors are responsible for certain maintenance parameters. In his research, Ebeling used multiple regression techniques to identify parametric equations which predicted mean flying hours between failures as a function of vehicle design and performance specifications (Ebeling, 1992). Because data collection on current spacecraft systems is difficult to obtain, data is assumed to be similar to those of comparable existing aircraft. Therefore, estimates of existing aircraft data can be used in regression analysis (Ebeling, 1992). In his study, Ebeling obtained and utilized maintenance WUC data at the two-digit (subsystem) level of eight bomber, fighter, and transport aircraft to estimate reliability and maintainability parameters of new space vehicles (Ebeling, 1992). An additional study resulted in the development of parametric models for estimating reliability and maintainability characteristics directly based on vehicle size and technology support level (Unal, et al., 2000).

Human Factors Affecting Maintenance

There are many different factors or variables which have an effect on maintenance turn around times. The DOD recognizes this fact and has published many publications in the area of human factors as well as engineering and ergonomics. Specifically used during the design phase of military systems, these guidelines serve as a basis for exploratory research in determining the effects of engineering on maintenance technician performance. Based on the Department Of Defense Handbook For Human Engineering Design Guidelines, there are over 20 factors which directly affect human performance (MIL-HDBK-759C, 1995).

Additionally, the U.S. Department of Transportation and the Federal Aviation Administration (FAA) has published a Human Factors Design Standards handbook which identifies anthropometry and biomechanics interactions with human kinesiology. This handbook serves as a guide to identify certain limits of human physical potential such as reach, flexibility, strength and dexterity (U.S. DOT, 2003). Intended to make equipment maintenance uncomplicated, expeditious, and safe, the formulation of human factors guidelines for maintenance focuses on organizing maintenance actions into individual system modules (U.S. DOT, 2003). In addition, accessibility, built-in testing, diagnostics and fault isolation are identified as key factors in maintenance times.

From an aircraft maintenance perspective, human factors can be defined by identifying the limitations of human performance. These limitations can affect maintenance technicians physically, physiologically, psychologically, or pathologically (Wurmstein, et al., 2004). Examples of physical factors include reduced capabilities due to restrictions in vision, hearing, or physical access (Wurmstein, et al., 2004). An

illustration of a maintenance technician faced with a task involving difficult physical access to parts is shown in Figure 1.

Figure 1. Reduced Physical Access (Air Force, Photos, 2008)

The FAA is aware of the influence of certain factors on aircraft maintenance activities and has determined that "human factors is incorporated into every aspect of aviation maintenance" (FAA, 1998). Acting in its role as a federal regulator, the FAA defines human factors by placing the human at the center of any system and identifies the specific capabilities and limitations of humans within certain environments. Specific maintenance difficulties can be attributed to awkward workspace postures, heavy or awkward lifting, poor equipment control configuration, and repetitive actions (FAA, 1998). Figure 2 shows maintenance technicians performing a task which requires awkward overhead lifting.

Figure 2. Task Requiring Overhead Lifting (Air Force, Photos, 2008)

The maintainability of aircraft systems can be improved during the design phase if a focus on capacities and limitations of maintenance technicians is maintained (Majoros, 1989). As the cost of aircraft maintenance continues to rise, an examination into the following factors may identify areas for improvement: weight of component, dimensions, mounting provisions, location installation, number of technicians required, removal and replacement procedures, visual and physical access, lifting and carrying requirements, and safety considerations (Majoros, 1989). As Figure 3 shows, many maintenance tasks require the efforts of multiple technicians.

Figure 3. Task Requiring Multiple Technicians (Air Force, Photos, 2008)

When considering the effects of human factors on maintenance, it is important to understand the difference between maintainability and maintenance. Maintainability is a requirement which is normally considered during the design phase of system development while maintenance is often considered the consequence or result of the design (Hoff, 1988). Examples of the qualitative factors of maintainability and maintenance are: on versus off equipment maintenance, accessibility, serviceability, ease of maintenance, safety, quantity, skill levels, specialty codes, technical data, and support equipment (Figure 4) required to maintain the system (Hoff, 1988).

Figure 4. Use of Specialized Equipment (Air Force, Photos, 2008)

Through the examination of specific space-based vehicle systems, the relationships between key operational factors and the attainment of operationally responsive spacelift can be identified (McCleskey,et al., 2004). During the design phase of the space shuttle, many of the key drivers were considered, but unfortunately, the final product lacked the incorporation of the factors. Therefore, when any space system is designed, the following key variables should be considered: number and complexity of interfaces, number and type of different fluids, number of separate Ground Support

Equipment (GSE) items (Figure 5), and unique vehicle payloads (McCleskey,et al., 2004).

Figure 5. Ground Support Equipment, Engine Stand (Air Force, Photos, 2008)

In addition, McCleskey suggests significant impact to maintenance occurs as a result of accessibility constraints. These constraints involve the difference between ground-level versus elevated access requirements and internal versus external actions (McCleskey, et al., 2004). An example of these constraints is illustrated in Figure 6.

Figure 6. Repair Requiring Elevated Panel Removal (Air Force, Photos, 2008)

Summary

This chapter provided a review of background information designed to provide justification of the research through a presentation of supporting literature. The first section covered current spacelift objectives. The next section discussed RLV and RMLV history, development, and research. The third section provided an overview of Air Force maintenance documentation. The final section presented the significance of parametric analyses between maintenance or aircraft indicators and influential factors. The next chapter outlines the methodology employed in this research.

III. Methodology

Introduction

This chapter describes the methods used to develop parametric models of MILEPOST process times. The first section provides an explanation of how the processes were organized. The next section outlines the methods used to collect and analyze the required data.

Organization of MILEPOST Processes

Process Overview

As briefly described in Chapter II, the complete MILEPOST model is comprised of three individual Arena sub-models. Driving the model output are 176 individual maintenance processes. Together, these processes provide an estimated timeline for all theoretical RMLV activities within the three stages of RMLV regeneration: post-landing, ground maintenance, and pre-launch operations. Within MILEPOST, these estimated processes are categorized by “Main Operation.” The three main operation categories are post-flight, maintenance, and integration.

Since the main focus of this research falls on refining the process times an evaluation of the times within the model was necessary. The previous researchers who developed MILEPOST and determined its activities, gathered estimates for each process in the model and then built a triangular distribution around each estimate (Stiegelmeier, 2006). Triangular distributions utilize minimum, most likely, and maximum values for each parameter of interest. The most likely process times were gathered for the MILEPOST activities using similar processes of existing air and space vehicles. The

minimum value was calculated by subtracting 10 percent from the most likely value, while the maximum value was calculated by adding 40 percent to the most likely value (Stiegelmeier, 2006).

Calculation of Process Mean

In order to properly evaluate MILEPOST process times, each individual process mean was calculated. Due to the asymmetric nature of the triangular distributions used, the mode or most likely value is not equivalent to the mean of the distribution. Therefore, the following formula was used to calculate the mean of each process (Banks, et al., 2005):

$$\text{Mean (Triangular)} = \frac{\text{Min Value} + \text{Most Likely} + \text{Max Value}}{3}$$

Identifying Factors affecting Maintenance

Applying human factors principles during the development stage of any product development has been determined to improve the overall productivity, quality and safety of the end product (Getty and Aust, 1997). Due to the current critical need of military space operations, the Air Force is aware that in order to achieve safe, reliable, affordable, and routine access to and from space, considerations of human factors interactions during maintenance must be included in the design of the system (Kolodziejski and Sturmer, 2001). Furthermore, employing modern analytical techniques in modeling and analyzing human interactions with system designs will increase the fidelity of the results used to serve as a decision tools (Getty and Aust, 1997).

As previously identified in Chapter 2, there are many different factors or variables which have an effect on maintenance task completion times. Table 2 identifies the key

human factors which affect the regeneration actions of processes found within the MILEPOST RMLV simulation model.

Table 2: Factors Affecting Maintenance Actions

FACTORS AFFECTING MAINTENANCE ACTIONS	
(Majoros, 1989)	**(Hoff, 1988)**
Weight of component	On Equipment vs Off Equipment
Component envelope (Dimensions)	Accessibility
Mounting provisions and connections	Serviceability
Location installation	Ease of maintenance
Number of personnel required	Safety procedures/equipment
Removal and installation procedures	Quantity of technicians
Visual and physical access	Skill levels of technicians
Lifting / carrying requirements	Specialty codes of personnel
Safety considerations	Technical data
	Support equipment required
(FAA, 1998)	**(McCleskey, et al., 2004)**
Awkward workspace posture	Number and complexity of interfaces
Heavy / Awkward lifting	Number and type of different fluids
Poor equipment control config	Number of Ground Support Equip (GSE) items
Repetitive actions	Unique payload

Determining Process Categories

The intention of this research is to determine parametric relationships between all MILEPOST processes and the factors which affect the time to complete the respective task. In considering all 176 processes, it was evident that the possible combinations of factors for each process were too numerous for the scope of this research. Therefore, MILEPOST processes were organized into five main categories of maintenance. The

categories of maintenance were determined through comparisons with existing examples used in previous studies.

In their study of determining where International Space Station and Skylab astronauts actually spend their productive time, Russell and Klaus utilized a comparison to a manufacturing plant in categorizing certain maintenance actions. They determined that maintenance actions can be organized into the following general categories (Russell and Klaus, 2006):

1. Maintenance of existing equipment
2. Maintenance of existing buildings/grounds
3. Equipment Inspection and Lubrication
4. Utilities Generation and Distribution
5. Upgrades, Installation of new equipment/buildings

Additionally, they identified the following, more operationally specific categories of maintenance (Russell and Klaus, 2006):

1. Inspections/Auditing
2. Remove/Replace
3. Equipment Operation
4. Cleaning
5. Routine Repair

Maintenance tasks are generally similar to each other in that the process which a technician follows to complete a maintenance action is similar from one repair to the next. Of course, as each repair task is accomplished, unusual difficulties may arise, but the basic steps followed will be the same (Cook, et al., 1973). In their analysis of the

maintainability of helicopter components, Cook and his colleagues conducted in-depth technical analyses of certain replacement tasks of helicopter parts. This involved identifying the functional relationship of the component to the system as a whole. Through researching aircraft technical manuals, maintenance handbooks, and troubleshooting charts the establishment of eight maintenance task elements was completed. The following eight categories of maintenance was established and utilized in their study (Cook, et al., 1973):

1. Fault isolation (troubleshooting)
2. Gaining access and securing doors, panels, fairing, etc.
3. Removal and replacement of other components for accessibility to the component in need of replacement
4. Removal and replacement of buildup components
5. Removal and replacement of the end assembly component
6. Draining and refilling of fluid supplies (oil, hydraulic fluid, etc.) and servicing or lubrication after repair or replacement
7. Adjustment, alignment, balancing, tracking, etc. after repair or replacement
8. Inspection during and after repair or replacement

Through a comparison of the previously established categories of maintenance with the processes in the MILEPOST model, this research determined and utilized the following five categories of maintenance in the analysis of parametric relationships:

1. Inspections / Checks / Diagnosis / Troubleshooting
2. Remove / Replace (Main Component)
3. Fluids / Hazards / Lubrication Actions
4. Adjustments / Calibrations / Post-Repair QC

5. Support Function (Equipment) / Pre-Repair / Prep Actions

All of the processes within MILEPOST were organized into one of the previous five categories of maintenance. See Appendix B for the complete categorical listing of MILEPOST processes.

Applying Factors to Process categories

The final preliminary step to reduce the complexity of the task of identifying the significant human factor variables which affect the model processes was in applying five key factors to the previously identified five maintenance categories. Based on discussions with aircraft engineers, Crew Chiefs, Quality Assurance, and aircraft analysis personnel (subject matter experts) of aircraft maintenance units, the following factors were applied to each respective category of maintenance:

<u>Inspections / Checks / Diagnosis / Troubleshooting</u>

Number of Interfaces to interrogate

Specialized Equipment Required

Internal or External Access

Number of Personnel Required

Immediate results or Additional Analysis Required

<u>Remove / Replace (Main Component)</u>

Weight of component

Size of component

Number of access panels needing removed

Number of Ground Support Equipment (GSE) items required

Number of technicians required

Fluids / Hazards / Lubrication Actions

Fluid/fuel volume

Number of GSE items

Number of technicians required

Number of different Air Force Specialties required

Internal or External Access

Adjustments / Calibrations / Post-Repair QC

Number of Personnel Required

Number of different Air Force Specialties required

Internal or External Access

Repair Surface Area

Number of GSE items

Support Function (Equipment) / Pre-Repair / Prep Actions

Number of technicians required

Number of GSE items

Weight of component / Support Equipment

Internal or External Access

Any Lifting Required

The primary focus was on Quantitative factors due to the practical applications of regression models.

Data Collection

Work Unit Code (WUC) Structure

The WUC consists of five characters, and is used to identify the system, subsystem, or component on which maintenance is required, or was accomplished. The primary purpose of WUCs is to identify the specific hardware component on which some maintenance action has been accomplished (Air Force, MIL-PRF-38769D, 1996). The first two positions identify the end item of equipment. The third and fourth characters include major assemblies and subassemblies, and correspond to the first and second levels of assembly. The fifth position of the WUC includes reparable and recoverable components, and identifies the lowest level of assembly below the end items (Air Force, MIL-PRF-38769D, 1996).

Restrictions on the use of WUCs are also presented in MIL-PRF-38769D. For example, Work unit codes are not to be created and "assigned to locations, general terms, or homogeneous group titles and shall not be assigned to common hardware or soft goods, such as nuts, bolts, washers, clamps, seals, packing, and O-rings" (Air Force, MIL-PRF-38769D, 1996). Any type of work on these common items should be reported against the coded assembly on which the item is attached.

As previously mentioned in Chapter II, during the acquisition of new systems, Air Force Material Command's (AFMC) equipment managers create, assign and publish WUC manuals for every new weapon system (Air Force, T. O. 00-20-2, 2007). These manuals are subsequently used to provide unique codes which enable the collection, storing, and retrieving of Air Force maintenance data. The data are used by all

individuals within the Air Force maintenance system (Air Force, T. O. 00-20-2, 2007). Appendix A within MIL-PRF-38769D outlines the specific steps to be utilized when creating WUC manuals.

When creating WUCs, the use of systems engineering data, equipment maintenance analysis data, and contract end item detail specifications shall be maximized. When assigning and grouping WUCs, high correlations should be sought after between the component end item and the organization and categorizing of WUCs. Additionally, when available, WUC manual preparation requires illustrated parts breakdown to aid in identifying the specific level of assembly (Air Force, MIL-PRF-38769D, 1996).

Additional instructions within the WUC preparation manual outline that during the creation of WUC manuals, authors should focus on organizing the codes in a functional system concept. Using this approach, components which make up a system are grouped together regardless of whether the units are hydraulic, electrical, pneumatic, electronic, or mechanical in nature (Air Force, MIL-PRF-38769D, 1996). Furthermore, the components grouped as a functional system should be only those components which function together to enable the actual function of the entire system.

In addition to the specific component codes, WUC manuals are also designed to list Support general codes and Scheduled and special inspections codes. Support general codes are established and used to record repetitive tasks of a general nature. Therefore, support codes and scheduled and special inspections codes are not used for recording malfunctions, repair, Not Repairable This Station (NRTS), or condemnation actions (Air Force, MIL-PRF-38769D, 1996).

Further guidance is presented which dictates the proper use of alphabetic and numeric codes. For example "upper-case letters A through Z (excluding I and O) and numbers 0 through 9 shall be utilized for WUC assignments. Additionally, the letters I and O shall not be used in any WUC to prevent confusion with the numbers one and zero" (Air Force, MIL-PRF-38769D, 1996).

Once created, the WUC manual must meet certain minimum verification requirements prior to being published and distributed for use. The minimum verification steps shall ensure the following (Air Force, MIL-PRF-38769D, 1996):

1. Suitability of the work unit code manuals for the intended environment.
2. Usability by the intended users.
3. Compatibility with other government systems.

Aircraft Data Collection

As mentioned in Chapter I of this thesis, the focus of this study will be limited to the evaluation of military aircraft which currently exist today. To improve previous analyses which have established a baseline model, the RMLV operations of the future may be better correlated to additional existing aircraft in addition to the space shuttle or B-2 bomber. Therefore, the collection of accurate data from four aircraft types existing today (B-2, C-5, KC-135, and F-16) is paramount in providing the necessary information needed to perform statistical regression analysis.

Similar to the methodology used by Ebeling in his study, this research utilized maintenance data of a bomber, fighter, tanker, and transport aircraft to estimate the maintainability parameters of an RMLV (Ebeling, 1992). C-5, F-16, and KC-135 aircraft were included in this research due to the close proximity of local Air Reserve and Air

National Guard units. The inclusion of B-2 aircraft data was deemed critical due to the similarities of unique maintenance requirements such as the Thermal Protection System of the B-2 to a space vehicle. Additionally, a significant portion of the MILEPOST data is based primarily on shuttle and B-2 data due to the closer similarity of the RMLV concept to Shuttle inter-launch maintenance activities (Pope, 2006).

Initial contact was made with several aircraft units and a list of potential maintenance Subject Matter Experts (SME) on each weapon system was identified. The SMEs were contacted and those who were willing to assist with this study were sent a form designed to gather data on specific maintenance task times and the factors which affect the maintenance action. The SMEs who participated represent Aircraft Systems Engineers from Lockheed-Martin and Northrup-Grumman, Career Maintenance Officers and Crew Chiefs, Maintenance Quality Assurance personnel, and Maintenance analysts. Appendix C provides a copy of the complete aircraft data form used to collect maintenance task times and related factor data.

Data provided by the SMEs was based on recorded historical data, when available. When little or no documented data was available, the data provided was based on the SME's personal experience involved with the performance of the most frequent type of maintenance action which best correlated to the task time or factor in question.

Data Regression Analysis

Regression analysis models and identifies relationships between response variables (dependent variables) and a number of predictors (independent variables) (McClave et al. 2005). The analysis between only one dependent variable and a unique independent variable is called simple regression, while the analysis of a set of

independent variables to predict the relationship to a dependent variable is known as multiple regression.

Since this research involves the analysis of maintenance task times with five independent variables, multiple linear regression techniques were utilized in creating parametric models. During this analysis, general first order form models were constructed and took the following mathematical form (McClave, et al., 2005):

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + \varepsilon$$

Where:

y = the dependent or response variable (Maintenance Task Time),

$X_1, X_2, \ldots X_k$ = the independent or predictor variables,

$E(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k$ is the deterministic portion of the model,

ε is the random error component, and

β_k determines the contribution of the k^{th} independent variable

According to McClave, et al., the following steps are used to develop multiple regression models:

1. Hypothesize the deterministic component of the model. This component relates the mean $E(y)$, to the independent variables $X_1, X_2, \ldots X_k$. This involves the choice of the independent variables to be included in the model.
2. Use sample data to estimate the unknown model parameters $\beta_0, \beta_1, \beta_2, \ldots \beta_k$.
3. Specify probability distribution of the random error term, ε, and estimate the standard deviation, σ, of the distribution.
4. Check that the assumptions on ε are satisfied, and make model modifications, if necessary.

5. Statistically evaluate the usefulness of the model.

6. When satisfied that the model is useful, use it for prediction, estimation and other purposes.

The previous described steps were utilized in this research to construct individual regression models.

The specific regression techniques used in this research were completed using the statistical software package, JMP 6.0. When utilizing this software, this author employed the technique of backward stepwise regression. This technique includes all independent variables in an original model. After the initial model was analyzed, the variables which demonstrated the most significance (p-value) were retained while those with poor significance were removed from the original model. Due to the small sample sizes utilized in this analysis, a normally impractical p-value of 0.4 was used to initially allow the variable to be incorporated into the model and to set the baseline for further research. The reduced model was re-analyzed in this fashion until a final model was attained which demonstrated a desired level of significance and predictive strength (r^2).

The value of the resulting r^2 result is known as the coefficient of determination. This coefficient is used to measure the usefulness of the model by measuring how much the independent variables contribute in predicting the value of the independent variable (McClave, et al., 2005). Generally, on a scale of 0 to 1.0, the higher the r^2 value, the stronger the model will be in predicting future values. Technically, the coefficient of determination represents the portion of the total sample variability around the predicted dependent variable that can be explained by the linear relationship between the dependent and independent variables (McClave, et al., 2005).

Experimental Design

A primary goal of this research effort is to provide an accurate assessment of the data within the MILEPOST model in order to determine more robust maintenance process times for use in the RMLV modeling effort, thus adding fidelity and validity to the ongoing efforts within the RMLV program.

To determine if the factors chosen in this study have an affect on the output of the MILEPOST model, an experiment was designed and conducted. Experimental designs are conducted to determine the effect of one or more variables on the response. In the performance of these experiments, variables utilized are evaluated at predetermined levels. These levels determine the value of the factors used. The combinations of variables with specific levels used form the treatments of the experiment (McClave, et al., 2005). For example, a two level full factorial experimental design with four factors would result in the testing of 16 treatments as listed in Table 3.

Table 3: Two Level-Four Factor Treatments

	Factor and Level			
Treatment #	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
1	-	-	-	-
2	+	-	-	-
3	+	+	-	-
4	+	-	+	-
5	+	-	-	+
6	-	+	-	-
7	-	+	+	-
8	-	+	-	+
9	-	-	+	-
10	-	-	+	+
11	+	+	+	-
12	-	+	+	+
13	+	-	+	+
14	+	+	-	+
15	+	+	+	+
16	-	-	-	+

To determine if any of the factors have a significant affect on the response, an Analysis of Variance (ANOVA) test is performed. The ANOVA test utilizes hypothesis testing to compare the means between two or more treatments. ANOVA testing employs the comparison of two measures of variability to compare means; the Mean Square for Treatment (MST) and the Mean Square for Error (MSE) (McClave, et al., 2005). If the resulting ratio of the MST to the MSE is significantly large enough, the null hypothesis, that all treatment means are equal, would be rejected. If the null hypothesis is rejected, there is statistically significant evidence to conclude that at least 2 of the treatment means are different (McClave, et al., 2005).

Upon concluding that at least two treatment means differ, additional statistical analysis must be conducted to determine specific relationships between every set of treatment means. This research utilized the Tukey method for pairwise comparisons of treatments with equal sample sizes. The specific steps used to complete the experiment used in this thesis was accomplished using JMP 6.0 statistical software.

Summary

Chapter III outlined the methods used to complete this research effort. Presented was the process of organizing MILEPOST process data followed by the methods employed in gathering relative data and conducting the analysis. The next chapter presents the results and analysis of this thesis.

IV Results and Analysis

Introduction

This chapter provides a presentation of the analysis and results of this study. The chapter begins with the construction of a notional WUC structure, is followed by the creation of parametric models using regression techniques, lists model limitations, offers simple mean comparisons and ends with a summary of the results.

Development of MILEPOST WUC Table

Followed guidance listed in "Appendix A" of MIL-PRF-38769D (USAF) which describes in great detail how to create WUC structures. Key tables utilized were tables IV, VIII, IX, and XIII. These tables listed the generic codes for a "Ground Launched Missile or Spacecraft." Copies of these tables are listed in Appendix D of this report.

A complete notional WUC structure was developed and is listed in Appendix E of this thesis.

Verification

According to MIL-PRF-38769D, once a WUC manual is created, the manual must meet certain minimum verification requirements prior to being published and distributed for use. The minimum verification steps shall ensure the following (Air Force, MIL-PRF-38769D, 1996):

1. Suitability of the work unit code manuals for the intended environment.
2. Usability by the intended users.
3. Compatibility with other government systems.

The notional WUC table created during this research was presented to a Systems Analyst of the Reliability and Maintainability Information System (REMIS) for review

and validation. Specifically, the request was for an expert review of the notional WUC structure to determine plausibility and to determine if there would be any difficulties (content or compatibility) incorporating this WUC structure and the MILEPOST processes into REMIS.

Upon review and minor corrections noted it was determined that the WUC structure created during the process of completing this thesis as well as the MILEPOST processes would easily be incorporated into REMIS without causing any compatibility issues. As such, the WUCs and processes are considered suitable and usable by the space maintenance community. Therefore, through an expert review, the notional WUC structure was verified and validated. Comments provided by the REMIS system office are listed in Appendix F.

Data collection using the created MILEPOST WUC structure

Intent

The original method for data collection designed for this research was to utilize the WUCs established for the processes in MILEPOST for extracting maintenance task times out of REMIS, the Air Force's reliability and maintainability information system.

Limitation and Alternative Method

A REMIS report was generated for all B-2, C-5, KC-135, and F-16 aircraft WUCs which have been reported on during the past five years. This report was generated using Mean Time to Repair and Mean Repair Times as the main parameters.

When the attempt was made to match WUC created from the processes in MILEPOST to the WUCs listed in REMIS by aircraft, it became evident that it would not be possible to collect the required data for this study via this method. This shortfall can

be attributed to two main reasons. First, although the processes of existing aircraft and the processes in MILEPOST are similar, the WUC structures are created using different tables within MIL-PRF-38769D. This incompatibility at the highest level system code resulted in the inability to match processes. Additionally, the majority of tasks associated within the MILEPOST model are supportive in nature. As such these processes were coded using the support code tables for ground launched spacecraft found in MIL-PRF-38769D. Unfortunately, due to the broad nature of the support code categories, individual task times cannot be retrieved using REMIS. Therefore, the shortfalls experienced with data collection via REMIS resulted in the formulation of the data collection forms, as discussed in Chapter III of this paper.

Building Regression Models

All processes, for which an adequate amount of data was collected, were organized into one of the following five categories: 1) Inspections / Checks / Diagnosis / Troubleshooting, 2) Remove / Replace (Main Component), 3) Fluids / Hazards / Lubrication Actions, 4) Adjustments / Calibrations / Post-Repair QC, 5) Support Function (Equipment) / Pre-Repair / Prep Actions. Furthermore, depending on the category of each of the processes, the following basic regression models were formulated:

1. Inspections / Checks / Diagnosis / Troubleshooting:

$$y \text{ (Task Time)} = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5$$

Where:
X_1 = Number of Interfaces to interrogate
X_2 = Specialized Equipment Required
X_3 = Internal or External Access
X_4 = Number of Personnel Required
X_5 = Immediate results or Additional Analysis Required

2. Remove / Replace (Main Component)

$$y \text{ (Task Time)} = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5$$

Where:
X_1 = Weight of component
X_2 = Size of component
X_3 = Number of access panels needing removed
X_4 = Number of Ground Support Equipment (GSE) items required
X_5 = Number of technicians required

3. Fluids / Hazards / Lubrication Actions

$$y \text{ (Task Time)} = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5$$

Where:
X_1 = Fluid/fuel volume
X_2 = Number of GSE items
X_3 = Number of technicians required
X_4 = Number of different Air Force Specialties required
X_5 = Internal or External Access

4. Adjustments / Calibrations / Post-Repair QC

$$y \text{ (Task Time)} = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5$$

Where:
X_1 = Number of Personnel Required
X_2 = Number of different Air Force Specialties required
X_3 = Internal or External Access
X_4 = Repair Surface Area
X_5 = Number of GSE items

5. Support Function (Equipment) / Pre-Repair / Prep Actions

$$y \text{ (Task Time)} = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5$$

Where:
X_1 = Number of technicians required
X_2 = Number of GSE items
X_3 = Weight of component / Support Equipment
X_4 = Internal or External Access
X_5 = Any Lifting Required

Model Formulation:

The following regression models presented were formulated using JMP 6.0 and are presented in sequence of data research question:

Question 1. How long does it take to Fill (Load) Aircraft fuel tank(s) (considered empty)?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to Fill (Load) Aircraft fuel tank(s) (considered empty)?	120	150	120	15
LBS Fluid/fuel volume	167,000	332,500	200000	12,000
Number of GSE items	2	4	3	2
Multiple Techs required-(# of)	4	5	4	2
Multiple AFSCs required-(# of)	2	2	4	2
Internal Access? (1=Yes, 0=No)	0	1	1	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
95	1st stage fuel chill and fill	Integration
92	1st stage fuel chill and fill 1	Integration
89	1st stage fuel chill and fill 2	Integration
94	2nd stage fuel chill and fill	Integration

93	2nd stage fuel chill and fill 1	Integration
90	2nd stage fuel chill and fill 2	Integration
76	Fuel RP first stage	Integration
77	Fuel RP first stage 1	Integration
79	Fuel RP first stage 2	Integration
78	Fuel RP second stage	Integration
80	Fuel RP second stage 1	Integration
58	Load hypergolic fuel off pad	Integration
75	Load hypergolic fuel on pad	Integration

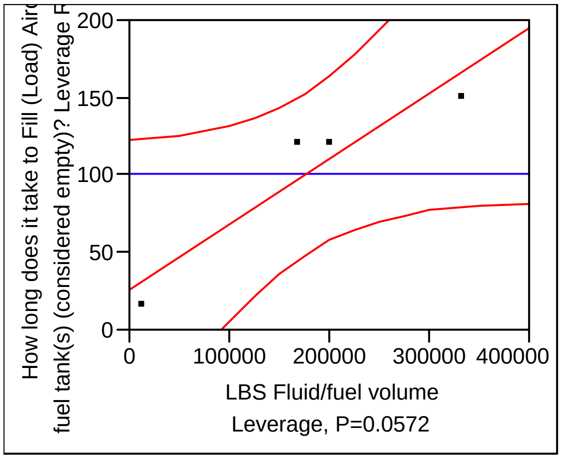
Summary of Fit

RSquare	0.888814
RSquare Adj	0.833221
Root Mean Square Error	24.182
Mean of Response	101.25
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	25.850139	22.40051	1.15	0.3678
LBS Fluid/fuel volume	0.0004239	0.000106	4.00	0.0572

Leverage Plot



Prediction Expression:

Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume

Model Analysis

With an r^2 value of 0.889, this model explains approximately 89 percent of the variation when used to predict the time it takes to perform fueling operations given a fuel volume. Furthermore, a p-value of 0.057 suggests that approximately 94 percent of the time, this model will explain the parametric relationship between the time that it takes to perform fueling operations and the volume of fuel required.

<u>Question 2.</u> How long does it take to Fill (Load) Aircraft LOX tank(s) (considered empty)?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to Fill (Load) Aircraft LOX tank(s) (considered empty)?	60	60	60	20
LITERS Fluid/fuel volume	100	100	100	5
Number of GSE items	2	2	1	2
Multiple Techs required-(# of)	2	1	1	2
Multiple AFSCs required-(# of)	2	1	1	2
Internal Access? (1=Yes, 0=No)	1	0	0	1

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
83	1st stage LOX chill and fill	Integration
85	1st stage LOX chill and fill 1	Integration
87	1st stage LOX chill and fill 2	Integration
84	2nd stage LOX chill and fill	Integration
86	2nd stage LOX chill and fill 1	Integration
88	2nd stage LOX chill and fill 2	Integration

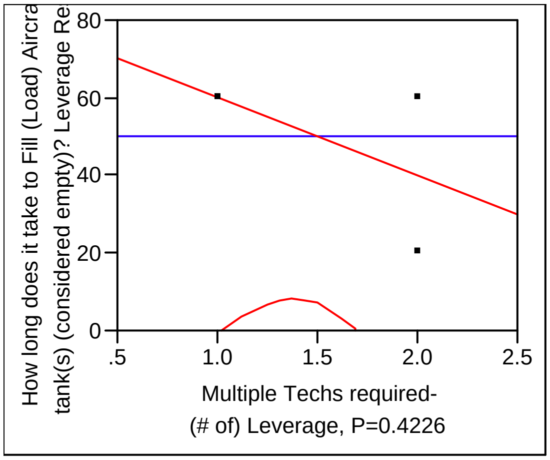
Summary of Fit

RSquare	0.333333
RSquare Adj	0
Root Mean Square Error	20
Mean of Response	50
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	80	31.62278	2.53	0.1271
Multiple Techs required-(# of)	-20	20	-1.00	0.4226

Leverage Plot



Prediction Expression:

Time to perform liquid oxygen filling = 80 + (-20)* Number of Technicians

Model Analysis

With an r^2 value of 0.333, this model explains approximately 33 percent of the variation when used to predict the time it takes to perform liquid oxygen filling operations given a tank volume. Therefore, this model is considered a very poor predictor and nearly non-useful. Furthermore, a p-value of 0.423 suggests that only approximately 57 percent of the time this model explains the parametric relationship between the time that it takes to perform liquid oxygen filling operations and the volume of tank(s) required.

<u>Question 6.</u> How long does it take to connect an expired engine to an engine stand?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to connect expired engine to engine stand?	360	300	270	240
Multiple Techs required-(# of)	4	4	2	3
Number of GSE items	2	4	2	2
Weight (lbs) of component / Spt Equip	3500	8000	5600	4000
Internal Access? (1=Yes, 0=No)	0	0	0	0
Lifting Required? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
120	Connect motor stand	Maintenance

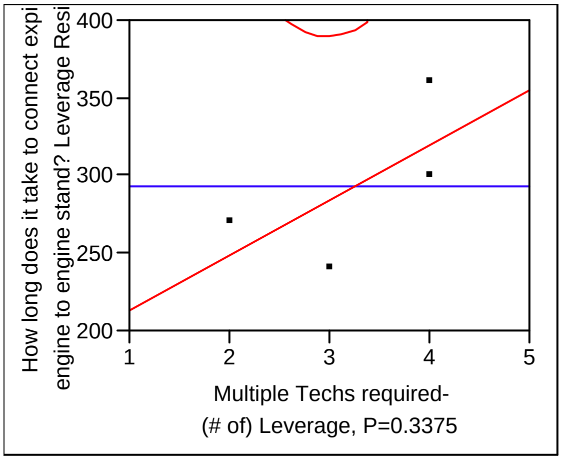
Summary of Fit

RSquare	0.438961
RSquare Adj	0.158442
Root Mean Square Error	47.00097
Mean of Response	292.5
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	177.27273	95.06414	1.86	0.2032
Multiple Techs required-(# of)	35.454545	28.34265	1.25	0.3375

Leverage Plot



Prediction Expression:

Time to connect an engine to a stand = 177.27273 + 35.454545*Number of technicians required

Model Analysis

With an r^2 value of 0.438961, this model explains approximately 44 percent of the variation when used to predict the time it takes connect a motor stand given the number of technicians required. Furthermore, a p-value of 0.3375 suggests that approximately 66 percent of the time this model explains the parametric relationship between the time that it takes to connect an engine to a stand and the number of maintenance technicians required. Therefore, this model is considered a very weak predictor of engine connection testing.

<u>Question 7.</u> How long does it take to test engine connection?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to test engine connection?	60	120	300	180
# Interfaces to interrogate	1	1	8	1
Specialized Equipment Required	0	1	1	1
Internal Access? (1=Yes, 0=No)	1	1	0	1
Multiple Techs required-(# of)	2	4	2	3
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	1	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
127	Connection Test	Maintenance

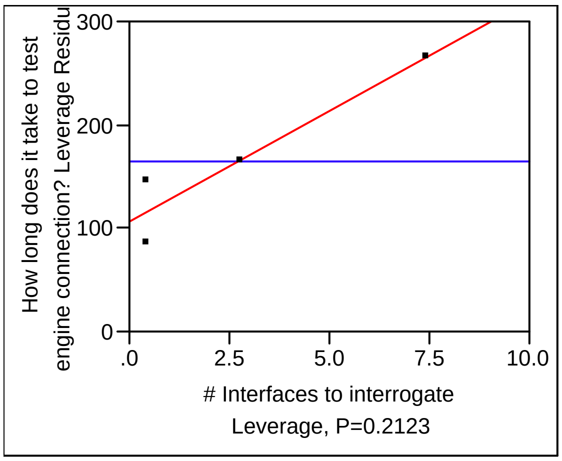
Summary of Fit

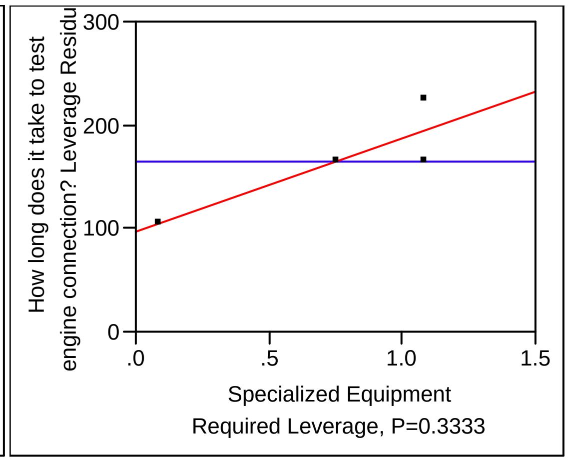
RSquare	0.942857
RSquare Adj	0.828571
Root Mean Square Error	42.42641
Mean of Response	165
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	38.571429	43.0709	0.90	0.5350
# Interfaces to interrogate	21.428571	7.423075	2.89	0.2123
Specialized Equipment Required	90	51.96152	1.73	0.3333
COMPLETE MODEL			F-STAT	0.2390

Leverage Plot





Prediction Expression:

Time to perform an Engine Connection Test = 38.571429 + 21.428571*Number of interfaces + Choose 0 (if no Specialized Equipment) OR 90 (if Specialized Equipment is required)

Model Analysis

With an r^2 value of 0.943, this model explains approximately 94 percent of the variation when used to predict the time it takes to perform an engine connection test given the number of interfaces interrogated and if any specialized equipment is required. Furthermore, an F-statistic of 0.2390 suggests that approximately 76 percent of the time, this model will explain the parametric relationships between the time that it takes to

perform an engine connection test given the number of interfaces interrogated and if any specialized equipment is required.

<u>Question 8.</u> How long does it take to disconnect engine stand?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to disconnect engine stand?	15	15	180	180
Multiple Techs required-(# of)	2	4	4	3
Number of GSE items	2	2	2	2
Weight (lbs) of component / Spt Equip	5000	10000	10000	5000
Internal Access? (1=Yes, 0=No)	0	0	0	1
Lifting Required? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
130	Disco stand	Maintenance
128	Disco stand and remove	Maintenance

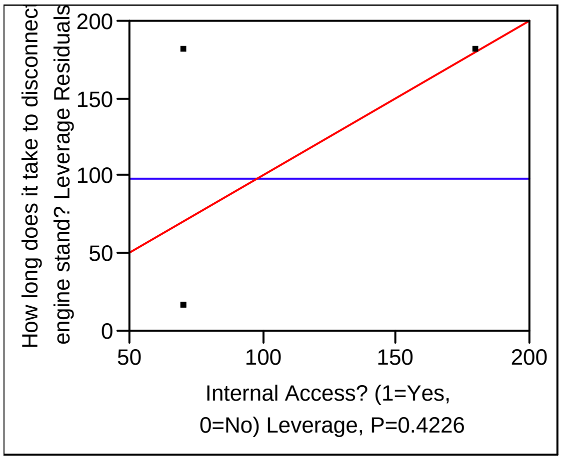
Summary of Fit

RSquare	0.333333
RSquare Adj	0
Root Mean Square Error	95.26279
Mean of Response	97.5
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	70	55	1.27	0.3311
Internal Access? (1=Yes, 0=No)	110	110	1.00	0.4226

Leverage Plot



Prediction Expression:

Time to disconnect an engine stand = 70 + Choose 0 (if no Internal Access) OR 110 (if Internal Access is required)

Model Analysis

With an r^2 value of 0.333, this model explains approximately 33 percent of the variation when used to predict the time it takes to disconnect an engine stand given whether or not internal access is required or not. Therefore, this model is considered a very poor predictor and nearly non-useful. Furthermore, a p-value of 0.423 suggests that only approximately 57 percent of the time that this model will correctly identify the parametric relationship between the time it takes to disconnect an engine stand given a possible requirement of internal access.

<u>Question 9.</u> How long does it take to replace engine filter?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to replace engine filter?	120	15	30	120
Weight (lbs) of component	2	5	1	2
Size (volume-cu in) of component	56.5	226	75.4	56.5
# of access panels needing removed	1	1	1	1
Number of GSE items	1	2	2	1
Multiple Techs required-(# of)	2	1	2	2

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
112	Filters 2	Maintenance
111	Filters 1	Maintenance

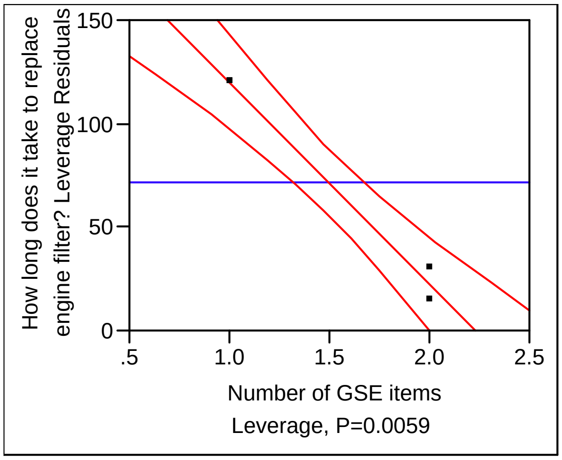
Summary of Fit

RSquare	0.988304
RSquare Adj	0.982456
Root Mean Square Error	7.5
Mean of Response	71.25
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	217.5	11.85854	18.34	0.0030
Number of GSE items	-97.5	7.5	-13.00	0.0059

Leverage Plot



Prediction Expression:

Time to replace an engine filter = 217.5 + (-97.5)*Number of GSE items used

Model Analysis

With an r^2 value of 0.988, this model explains approximately 99 percent of the variation when used to predict the time it takes to perform an engine filter change given the number of GSE items used. Furthermore, a p-value of 0.0059 suggests that approximately 99.4 percent of the time, this model will explain the parametric relationship between the time it takes to perform an engine filter change given the number of GSE items used.

The inverse regression line suggests that it is beneficial to use additional ground support equipment when changing an engine filter. Both the C-5 and KC-135 use an additional maintenance stand and complete engine filter changes in considerably less time in comparison to the B-2 and F-16.

<u>Question 11.</u> How long does it take to remove/replace standard/generic LRU?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to remove/replace standard/generic LRU?	120	30	15	60
Weight (lbs) of component	25	25	25	25
Size (volume-cu in) of component	1152	1188	1188	2592
# of access panels needing removed	1	0	0	1
Number of GSE items	1	0	0	2
Multiple Techs required-(# of)	2	1	1	2

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
113	LRU R2	Maintenance

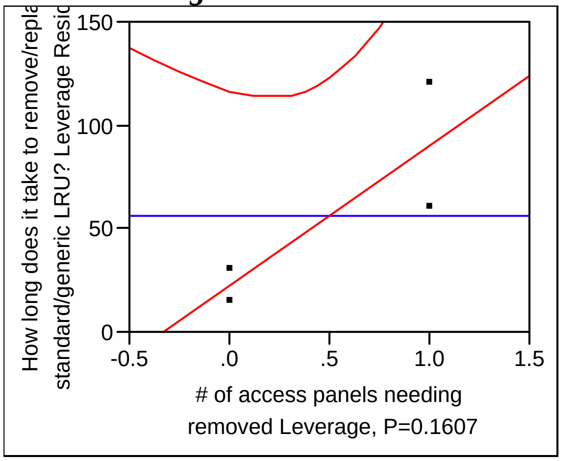
Summary of Fit

RSquare	0.704348
RSquare Adj	0.556522
Root Mean Square Error	30.92329
Mean of Response	56.25
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	22.5	21.86607	1.03	0.4117
# of access panels needing removed	67.5	30.92329	2.18	0.1607

Leverage Plot



Prediction Expression:

Time to remove and replace a standard LRU = 22.5 + 67.5*Number of panels removed

Model Analysis

With an r^2 value of 0.704, this model explains approximately 70 percent of the variation when used to predict the time it takes to remove and replace a generic line replaceable unit given the number of access panels which must be removed to gain access to the part. Furthermore, a p-value of 0.161 suggests that approximately 84 percent of the time, this model will explain the parametric relationship between the time it takes to perform an LRU replacement given the number of access panels needing removed.

<u>Question 14.</u> How long does it take to perform an avionics function check?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to perform an avionics function check?	60	240	120	120
# Interfaces to interrogate	2	1	8	1
Specialized Equipment Required	0	1	1	1
Internal Access? (1=Yes, 0=No)	1	1	0	1
Multiple Techs required-(# of)	2	2	2	2
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	1	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
101	Avionics Testing	Maintenance

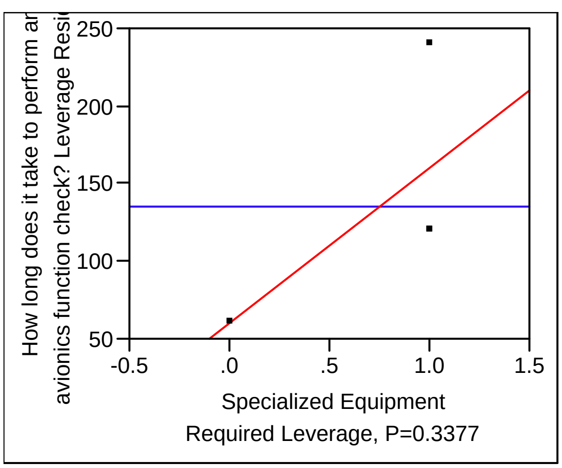
Summary of Fit

RSquare	0.438596
RSquare Adj	0.157895
Root Mean Square Error	69.28203
Mean of Response	135
Observations (or Sum Wgts)	4

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept		60	69.28203	0.87	0.4778
Specialized Equipment Required		100	80	1.25	0.3377

Leverage Plot



Prediction Expression:

Time to perform an avionics function check = 60 + Choose 0 (if no Specialized Equipment) OR 100 (if Specialized Equipment is required)

Model Analysis

With an r^2 value of 0.439, this model explains approximately 44 percent of the variation when used to predict the time it takes to perform an avionics function check given the number of Specialized Equipment items used. Furthermore, a p-value of 0.338 suggests that approximately 66 percent of the time, this model will explain the parametric relationship between the time it takes to perform an avionics function check and whether or not specialized equipment was required to perform the task. Therefore, this model is considered a very weak predictor of avionics function checks.

Question 15. How long does it take to perform a battery function check?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to perform a battery function check?	6	1	5	30
# Interfaces to interrogate	1	0	0	1
Specialized Equipment Required	0	0	0	1
Internal Access? (1=Yes, 0=No)	1	1	1	1
Multiple Techs required-(# of)	1	1	1	1
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
105	Battery testing	Maintenance

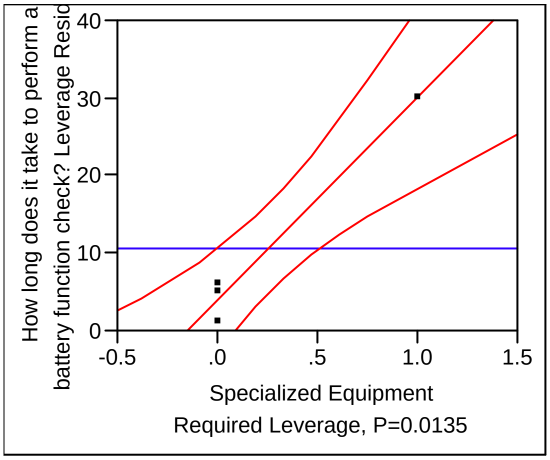
Summary of Fit

RSquare	0.973129
RSquare Adj	0.959693
Root Mean Square Error	2.645751
Mean of Response	10.5
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4	1.527525	2.62	0.1201
Specialized Equipment Required	26	3.05505	8.51	0.0135

Leverage Plot



Prediction Expression:

Time to perform a battery function check = 4 + Choose 0 (if no Specialized Equipment) OR 26 (if Specialized Equipment is required)

Model Analysis

With an r^2 value of 0.973, this model explains approximately 97 percent of the variation when used to perform a battery function check given whether or not specialized equipment was required. Furthermore, a p-value of 0.013 suggests that approximately 98 percent of the time, this model will explain the parametric relationship between the time it takes to perform a battery function check and whether or not specialized equipment was required to perform the task.

<u>Question 16.</u> How long does it take to perform a generic electrical connections check?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to perform a generic electrical connections check?	2	1	5	2
# Interfaces to interrogate	1	1	2	1
Specialized Equipment Required	1	1	1	1
Internal Access? (1=Yes, 0=No)	1	1	1	1
Multiple Techs required-(# of)	1	1	2	1
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
99	Electrical Connections 2	Maintenance
100	Upper Stage Electrical Connecting Point Testing	Maintenance

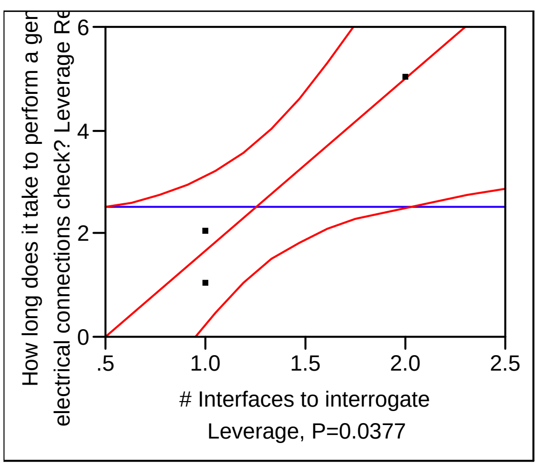
Summary of Fit

RSquare	0.925926
RSquare Adj	0.888889
Root Mean Square Error	0.57735
Mean of Response	2.5
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.666667	0.881917	-1.89	0.1994
# Interfaces to interrogate	3.3333333	0.666667	5.00	0.0377

Leverage Plot



Prediction Expression:

Time to perform an electrical connection check = (-1.666667) + 3.3333333*Number of interfaces to interrogate

Model Analysis

With an r^2 value of 0.923, this model explains approximately 92 percent of the variation when used to predict the time it takes to perform an electrical connection check given the number of interfaces which must be interrogated. Furthermore, a p-value of 0.038 suggests that approximately 94 percent of the time, this model will explain the parametric relationship between the time it takes to perform an electrical connection check given the number of interfaces to interrogate

Because this model has a negative β_0 (intercept) value, it must be assumed that the corresponding number of interfaces which must be interrogated during this task has to be greater than or equal to one. Otherwise, if there was a method to test an electrical connection without interrogating any interfaces, the time would be predicted to be less than zero, which of course, is not practical!

<u>Question 17.</u> How long does it take to perform engine function/status checks?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to perform engine function/status checks?	120	180	90	60
# Interfaces to interrogate	2	1	0	1
Specialized Equipment Required	0	1	1	1
Internal Access? (1=Yes, 0=No)	1	1	0	1
Multiple Techs required-(# of)	4	4	4	3
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
142	Engine checkout	Maintenance

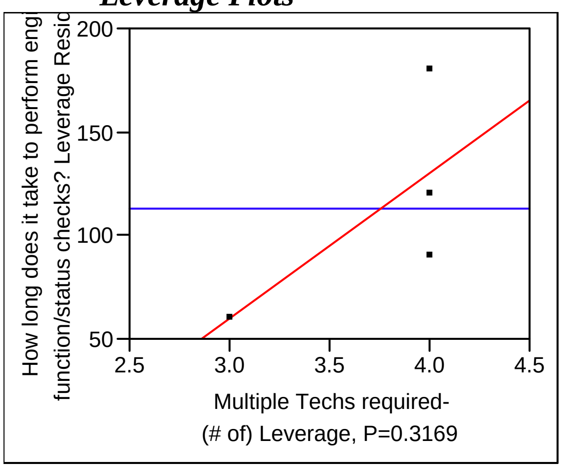
Summary of Fit

RSquare	0.466667
RSquare Adj	0.2
Root Mean Square Error	45.82576
Mean of Response	112.5
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-150	199.7498	-0.75	0.5310
Multiple Techs required-(# of)	70	52.91503	1.32	0.3169

Leverage Plots



Prediction Expression:
Time to complete an engine function check = (-150) + 70*Number of technicians required to perform this task

Model Analysis

With an r^2 value of 0.467, this model explains approximately 47 percent of the variation when used to predict the time it takes to complete an engine function check given the number of technicians required. Furthermore, a p-value of 0.317 suggests that

approximately 68 percent of the time, this model will explain the parametric relationship between the time it takes to complete an engine function check and given the number of technicians required.

Given a poor p-value, this model lacks practical use, although the leverage plots provide information which may prove to be useful on a very basic level. If utilized, careful consideration should be taken due to the negative β_0 (intercept) value. Users must be aware that the predicted values for the number of technicians must be greater than 150, otherwise the time predicted would be less than zero, which is not practical.

<u>Question 18.</u> How long does it take to perform engine controls checks?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to perform engine controls checks?	120	180	30	90
# Interfaces to interrogate	2	1	8	1
Specialized Equipment Required	0	2	1	1
Internal Access? (1=Yes, 0=No)	1	1	0	1
Multiple Techs required-(# of)	4	4	2	3
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
114	Engine Controls	Maintenance

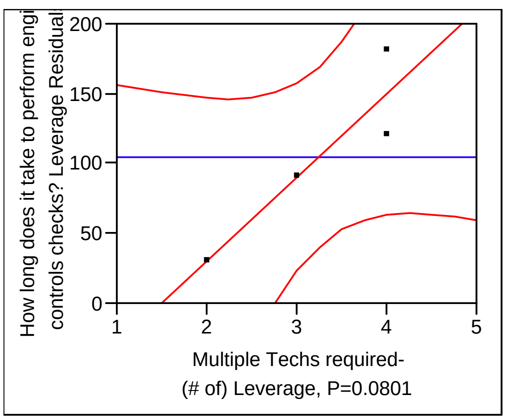
Summary of Fit

RSquare	0.846154
RSquare Adj	0.769231
Root Mean Square Error	30
Mean of Response	105
Observations (or Sum Wgts)	4

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept		-90	60.67799	-1.48	0.2763
Multiple Techs required-(# of)		60	18.09068	3.32	0.0801

Leverage Plot



Prediction Expression:

Time to perform an engine controls check = (-90) + 60*Number of maintenance technicians required to perform the job.

Model Analysis

With an r^2 value of 0.846, this model explains approximately 85 percent of the variation when used to predict the time it takes to perform an engine controls check given

the number of maintenance technicians required. Furthermore, a p-value of 0.081 suggests that approximately 92 percent of the time, this model will explain the parametric relationship between the time it takes to perform an engine controls check given the number of maintenance technicians required to complete the task.

If this model is utilized, careful consideration should be taken due to the negative β_0 (intercept) value. Users must be aware that it must be assumed that the number of maintenance technicians needed must be greater than or equal to 2, otherwise the overall task time predicted would be less than zero, which is not practical.

<u>Question 19.</u> How long does it take to perform engine diagnostics?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to perform engine diagnostics?	120	45	45	60
# Interfaces to interrogate	2	1	8	1
Specialized Equipment Required	0	1	1	1
Internal Access? (1=Yes, 0=No)	1	1	0	1
Multiple Techs required-(# of)	4	4	2	3
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
140	Engine Diagnostics	Maintenance

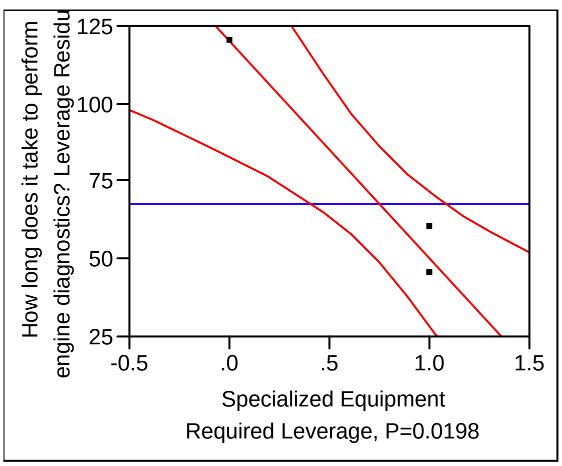
Summary of Fit

RSquare	0.960784
RSquare Adj	0.941176
Root Mean Square Error	8.660254
Mean of Response	67.5
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	120	8.660254	13.86	0.0052
Specialized Equipment Required	-70	10	-7.00	0.0198

Leverage Plot



Prediction Expression:

Time to perform engine diagnostics = 120 + Choose 0 (if no Specialized Equipment) OR (- 70) (if Specialized Equipment is required)

Model Analysis

With an r^2 value of 0.961, this model explains approximately 96 percent of the variation when used to perform engine diagnostics given if any specialized equipment is required. Furthermore, a p-value of 0.020 suggests that approximately 98 percent of the time, this model will explain the parametric relationship between the time it takes to perform engine diagnostics and whether or not specialized equipment was required.

<u>Question 20.</u> How long does it take to perform sensor tests/diagnostics?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to perform sensor tests/diagnostics?	60	.	240	60
# Interfaces to interrogate	1	1	8	1
Specialized Equipment Required	1	1	1	1
Internal Access? (1=Yes, 0=No)	1	1	0	1
Multiple Techs required-(# of)	2	4	2	2
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
143	Sensor Equipment	Maintenance

Summary of Fit

RSquare	0.604938
RSquare Adj	0.407407
Root Mean Square Error	69.28203
Mean of Response	135
Observations (or Sum Wgts)	4

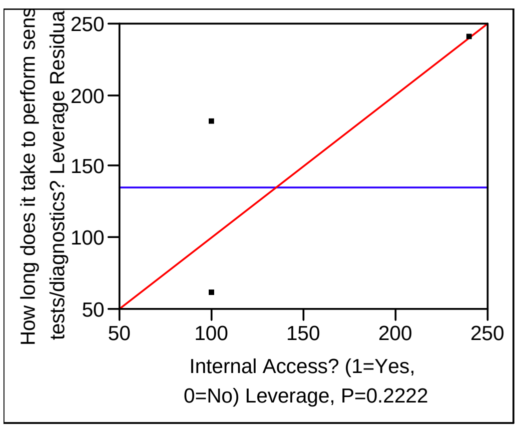
Parameter Estimates –Internal Access

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	240	69.28203	3.46	0.0742
Internal Access? (1=Yes, 0=No)	-140	80	-1.75	0.2222

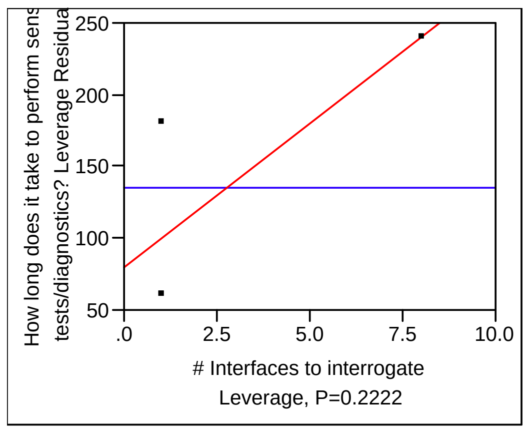
Parameter Estimates –Number of Interfaces

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	80	46.77344	1.71	0.2293
Internal Access? (1=Yes, 0=No)[1-0]	20	11.42857	1.75	0.2222

Leverage Plot-Internal Access



Leverage Plot-Number of Interfaces



Prediction Expression- Internal Access:

Time to perform sensor tests = 240 + Choose 0 (if no Internal Access) OR (-140) (if Internal Access is required)

Prediction Expression- Number of Interfaces:

Time to perform sensor tests = 80 + 20*Number of Interfaces interrogated

Model Analysis

The time that it takes to perform sensor tests can be modeled using a parametric relationship with the factor of internal access or a parametric relationship with the factor of the number of interfaces interrogated, but not both together. When combining these factors, erroneous and unexpected correlation results were produced. Therefore, each model can be used independently from one another. The following are the results for both models:

With each model displaying r^2 values of 0.605, the models explain approximately 61 percent of the variation when used to perform sensor tests given if any internal access is required or given the number of interfaces interrogated. Furthermore, a p-value of 0.222 suggests that approximately 78 percent of the time, these models explain their respective parametric relationships.

<u>Question 21.</u> How long to perform aft safety assessment?

Source Data:

	B-2	C-5	KC-135	F-16
How long to perform aft safety assessment?	60	12	10	10
# Interfaces to interrogate	0	0	0	0
Specialized Equipment Required	0	0	0	0
Internal Access? (1=Yes, 0=No)	0	1	0	1
Multiple Techs required-(# of)	2	1	1	1
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
164	Aft Safety Assessments	Post-Flight

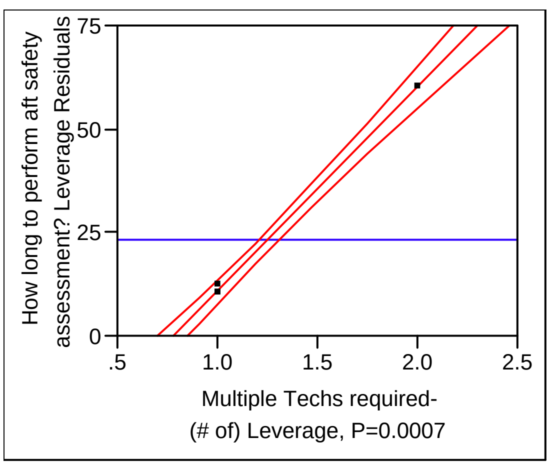
Summary of Fit

RSquare	0.998541
RSquare Adj	0.997812
Root Mean Square Error	1.154701
Mean of Response	23
Observations (or Sum Wgts)	4

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept		-38.66667	1.763834	-21.92	0.0021
Multiple Techs required		49.333333	1.333333	37.00	0.0007

Leverage Plot



Prediction Expression:

Time to perform aft safety assessments = (-38.66667) + 49.333333*Number of technicians required

Model Analysis

With an r^2 value of 0.998, this model explains nearly 100 percent of the variation when used to predict the time it takes to perform aft safety assessments given the number of maintenance technicians required. Furthermore, a p-value of 0.0007 suggests that approximately 99.93 percent of the time, this model will explain the parametric relationship between the time it takes to perform aft safety assessments given the number of maintenance technicians required to complete the task.

<u>Question 22.</u> How long to perform forward safety assessment?

Source Data:

	B-2	C-5	KC-135	F-16
How long to perform forward safety assessment?	60	12	10	10
# Interfaces to interrogate	0	0	0	0
Specialized Equipment Required	0	0	0	0
Internal Access? (1=Yes, 0=No)	0	1	0	0
Multiple Techs required-(# of)	2	1	1	1
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
145	Forward Safety Assessments	Post-Flight

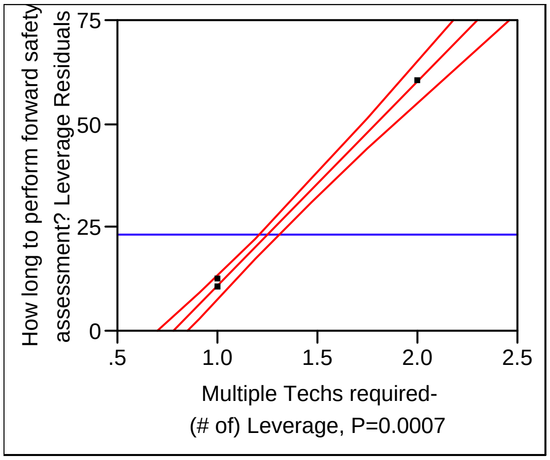
Summary of Fit

RSquare	0.998541
RSquare Adj	0.997812
Root Mean Square Error	1.154701
Mean of Response	23
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-38.66667	1.763834	-21.92	0.0021
Number of technicians required	49.333333	1.333333	37.00	0.0007

Leverage Plot



Prediction Expression:

Time to perform forward safety assessments = (-38.66667) + 49.333333*Number of technicians required

Model Analysis

With an r^2 value of 0.998, this model explains nearly 100 percent of the variation when used to predict the time it takes to perform forward safety assessments given the number of maintenance technicians required. Furthermore, a p-value of 0.0007 suggests that approximately 99.93 percent of the time, this model will explain the parametric relationship between the time it takes to perform forward safety assessments given the number of maintenance technicians required to complete the task.

Question 26. How long to Install ground lock pins & vent plugs?

Source Data:

	B-2	C-5	KC-135	F-16
How long to Install ground lock pins & vent plugs?	20	10	5	15
Multiple Techs required-(# of)	1	1	2	1
Number of GSE items	0	0	0	0
Weight (lbs) of component / Spt Equip	2	1	5	1
Internal Access? (1=Yes, 0=No)	1	0	0	1
Lifting Required? (1=Yes, 0=No)	0	0	1	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
150	Install Ground Lock Pins and Vent Plugs	Post-Flight

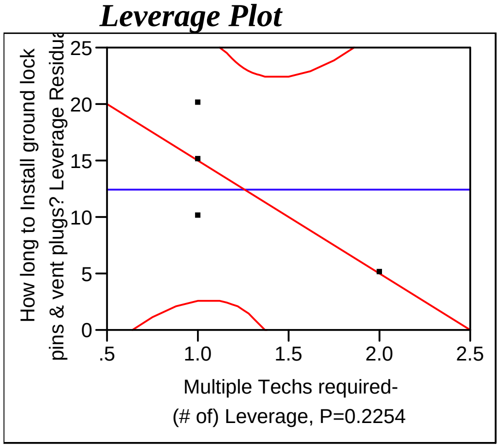
Summary of Fit

RSquare	0.6
RSquare Adj	0.4
Root Mean Square Error	5
Mean of Response	12.5
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	25	7.637626	3.27	0.0820
Multiple Techs required-(# of)	-10	5.773503	-1.73	0.2254

Leverage Plot



Prediction Expression:

Time to install ground lock pins and vent plugs = 25 + (-10)*Number of technicians required

Model Analysis

With an r^2 value of 0.6, this model explains 60 percent of the variation when used to predict the time it to install ground lock pins and vent plugs given the number of maintenance technicians required. Furthermore, a p-value of 0.225 suggests that approximately 77 percent of the time, this model will explain the parametric relationship between the time it takes to install ground lock pins and vent plugs given the number of maintenance technicians required to complete the task.

<u>Question 27.</u> How long to Install protective system (covers)?

Source Data:

	B-2	C-5	KC-135	F-16
How long to Install protective system (covers)?	20	30	15	15
Multiple Techs required-(# of)	2	2	2	1
Number of GSE items	1	2	0	0
Weight (lbs) of component / Spt Equip	10	10	5	2
Internal Access? (1=Yes, 0=No)	0	0	0	0
Lifting Required? (1=Yes, 0=No)	1	1	1	1

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
153	Install MPS and RMLV Protective Covers	Post-Flight

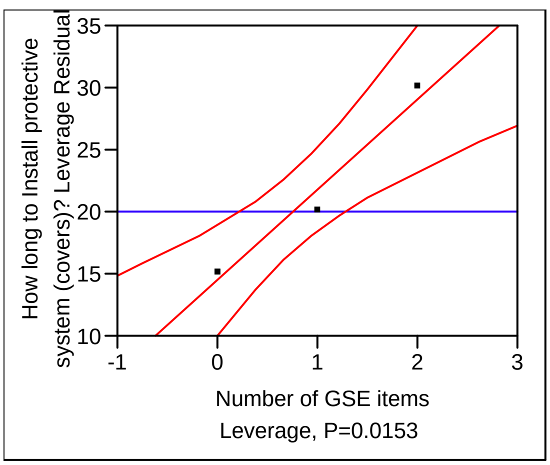
Summary of Fit

RSquare	0.969697
RSquare Adj	0.954545
Root Mean Square Error	1.507557
Mean of Response	20
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	14.545455	1.016395	14.31	0.0048
Number of GSE items	7.2727273	0.909091	8.00	0.0153

Leverage Plot



Prediction Expression:

Time to install protective covers = 14.545455 + 7.2727273*Number of GSE items

Model Analysis

With an r^2 value of 0.955, this model explains nearly 96 percent of the variation when used to predict the time it takes to install protective covers given the number of GSE items. Furthermore, a p-value of 0.0007 suggests that approximately 99.93 percent of the time, this model will explain the parametric relationship between the time it takes install protective covers given the number of GSE items required to complete the task.

<u>Question 30.</u> How long to position Ground support equipment?

Source Data:

	B-2	C-5	KC-135	F-16
How long to position Ground support equipment?	30	10	30	5
Fluid/fuel volume	0	0	0	0
Number of GSE items	2	1	1	2
Multiple Techs required-(# of)	2	1	1	1
Multiple AFSCs required-(# of)	1	1	1	1
Internal Access? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
166	Position External Store GSE	Post-Flight

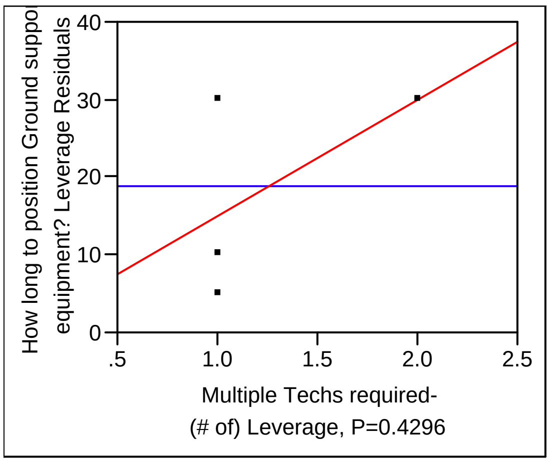
Summary of Fit

RSquare	0.325301
RSquare Adj	-0.01205
Root Mean Square Error	13.22876
Mean of Response	18.75
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0	20.20726	0.00	1.0000
Multiple Techs required-(# of)	15	15.27525	0.98	0.4296

Leverage Plot



Prediction Expression:

Time to position GSE = 0 + 15*Number of technicians required

Model Analysis

With an r^2 value of 0.325, this model explains approximately 33 percent of the variation when used to predict the time it takes to position GSE given the number of technicians required. Therefore, this model is considered a very poor predictor and nearly non-useful. Furthermore, a p-value of 0.423 suggests that approximately 57 percent of the time that this model explains the parametric relationship between the time that it takes to position GSE given the number of technicians required.

<u>Question 31.</u> How long does it take to Shutdown APU?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to Shutdown APU?	5	1	2	n/a
Multiple Techs required-(# of)	2	1	1	
Number of GSE items	0	0	0	
Weight (lbs) of component / Spt Equip	0	0	0	
Internal Access? (1=Yes, 0=No)	1	1	1	
Lifting Required? (1=Yes, 0=No)	0	0	0	

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
172	APU Shutdown	Post-Flight

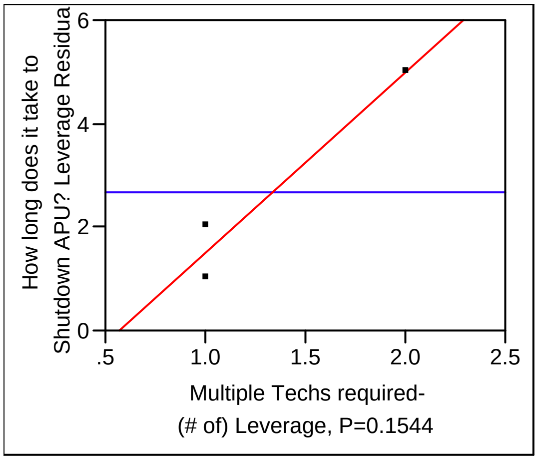
Summary of Fit

RSquare	0.942308
RSquare Adj	0.884615
Root Mean Square Error	0.707107
Mean of Response	2.666667
Observations (or Sum Wgts)	3

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-2	1.224745	-1.63	0.3498
Multiple Techs required-(# of)	3.5	0.866025	4.04	0.1544

Leverage Plot



Prediction Expression:

Time to shutdown an APU = (-2)+ 3.5*Number of technicians required

Model Analysis

With an r^2 value of 0.942 this model explains approximately 94 percent of the variation when used to predict the time it takes to shutdown an APU given the number of maintenance technicians required. Furthermore, a p-value of 0.154 suggests that approximately 85 percent of the time, this model will explain the parametric relationship between the time it takes to shutdown an APU given the number of maintenance technicians required to complete the task.

<u>Question 32.</u> How long does it take to Check Flight controls?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to Check Flight controls?	5	10	10	120
# Interfaces to interrogate	0	0	0	2
Specialized Equipment Required	0	0	0	2
Internal Access? (1=Yes, 0=No)	0	1	0	1
Multiple Techs required-(# of)	2	2	1	3
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
102	Flight Controls	Maintenance

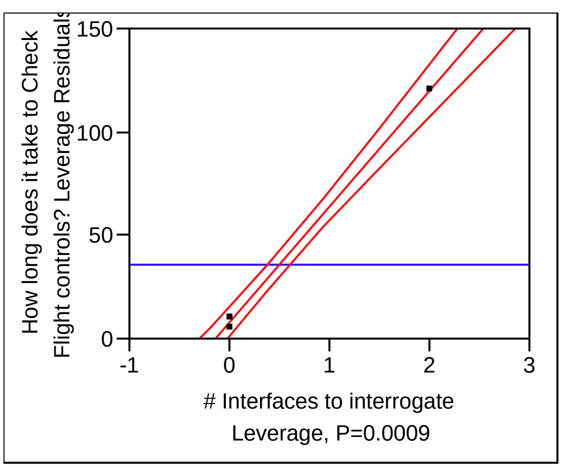
Summary of Fit

RSquare	0.998221
RSquare Adj	0.997332
Root Mean Square Error	2.886751
Mean of Response	36.25
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.3333333	1.666667	5.00	0.0377
# Interfaces to interrogate	55.833333	1.666667	33.50	0.0009

Leverage Plot



Prediction Expression:

Time to perform flight control checks = 8.3333333 + 55.833333*Number of interfaces interrogated

Model Analysis

With an r^2 value of 0.998, this model explains nearly 100 percent of the variation when used to predict the time it takes to perform flight control checks given the number of interfaces interrogated. Furthermore, a p-value of 0.0009 suggests that approximately 99.91 percent of the time, this model will explain the parametric relationship between the time it takes to perform flight control checks given the number of interfaces interrogated when completing the task.

<u>Question 33</u>. How long does it take to Perform a lubrication check?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to Perform a lubrication check?	60	60	15	120
# Interfaces to interrogate	0	0	0	0
Specialized Equipment Required	1	1	1	1
Internal Access? (1=Yes, 0=No)	0	0	0	0
Multiple Techs required-(# of)	4	1	1	1
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	0	1

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
110	Lubrication check	Maintenance

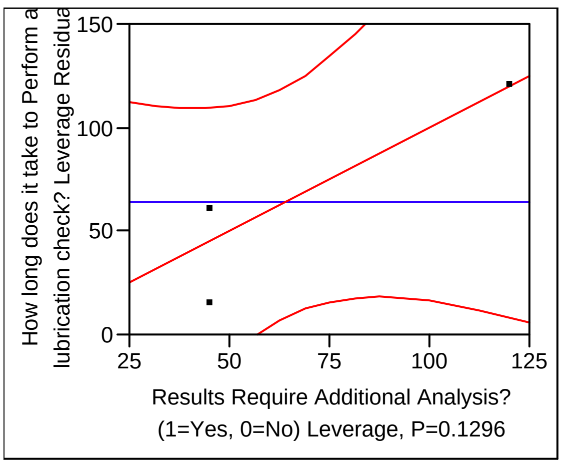
Summary of Fit

RSquare	0.757576
RSquare Adj	0.636364
Root Mean Square Error	25.98076
Mean of Response	63.75
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	45	15	3.00	0.0955
Results Require Additional Analysis? (1=Yes, 0=No)[1-0]	75	30	2.50	0.1296

Leverage Plot



Prediction Expression:

Time to perform a lubrication check = 45 + Choose 0 (if no additional analysis is required) OR 75 (if additional analysis is required)

Model Analysis

With an r^2 value of 0.758, this model explains nearly 76 percent of the variation when used to predict the time it takes to perform a lubrication check given if additional analysis is required or not. Furthermore, a p-value of 0.123 suggests that approximately 88 percent of the time, this model will explain the parametric relationship between performing a lubrication check and whether or not any additional analysis is required to complete the task.

<u>Question 35.</u> How long does it take to Perform Hydraulic Fluid Condition Check?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to Perform Hydraulic Fluid Condition Check?	60	4	30	10
# Interfaces to interrogate	0	0	0	0
Specialized Equipment Required	1	0	1	1
Internal Access? (1=Yes, 0=No)	1	0	1	0
Multiple Techs required-(# of)	2	1	2	1
Results Require Additional Analysis? (1=Yes, 0=No)	1	0	0	1

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
109	hydraulic condition	Maintenance

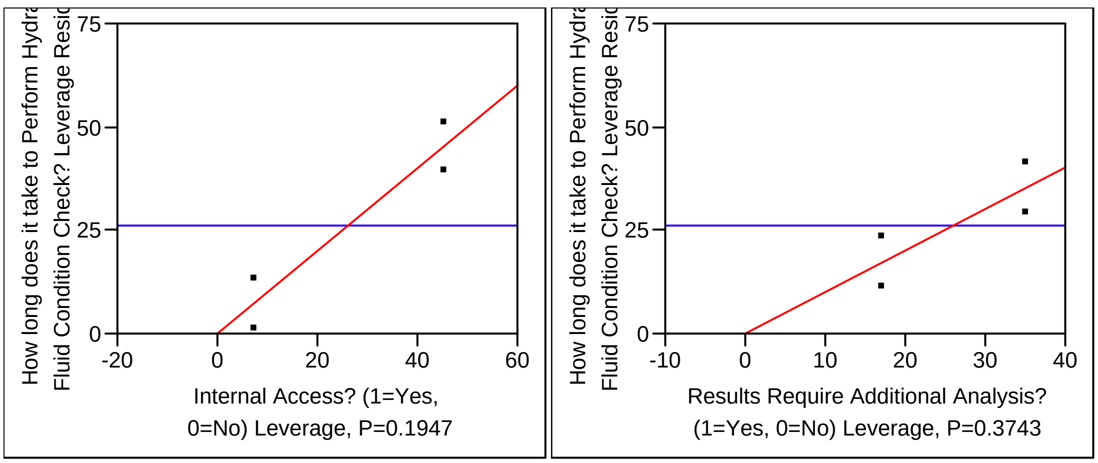
Summary of Fit

RSquare	0.924686
RSquare Adj	0.774059
Root Mean Square Error	12
Mean of Response	26
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-2	10.3923	-0.19	0.8790
Internal Access? (1=Yes, 0=No)[1-0]	38	12	3.17	0.1947
Results Require Additional Analysis? (1=Yes, 0=No)[1-0]	18	12	1.50	0.3743
COMPLETE MODEL			F-STAT	0.2744

Leverage Plots



Prediction Expression:

Time to perform hydraulic fluid condition checks = (-2) + Choose 0 (if internal access is required) OR 38 (if additional analysis is required) + Choose 0 (if no additional analysis is required) OR 18 (if additional analysis is required)

Model Analysis

With an r^2 value of 0.925, this model explains approximately 92.5 percent of the variation when used to predict the time it takes to perform a hydraulic fluid condition check given if internal access is required or not and if additional analysis is required or

not. Furthermore, a F-statistic of 0.274 suggests that approximately 73 percent of the time, this model will explain the parametric relationship between performing a hydraulic fluid check and whether or not additional analysis or internal access is required to complete the task.

<u>Question 36.</u> How long does it take to Perform Hard landing inspection on tires/wheels?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to Perform Hard landing inspection on tires/wheels?	10	5	480	120
# Interfaces to interrogate	1	0	0	0
Specialized Equipment Required	0	0	2	1
Internal Access? (1=Yes, 0=No)	1	0	0	0
Multiple Techs required-(# of)	2	1	2	2
Results Require Additional Analysis? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
117	Landing Gear and tires	Maintenance

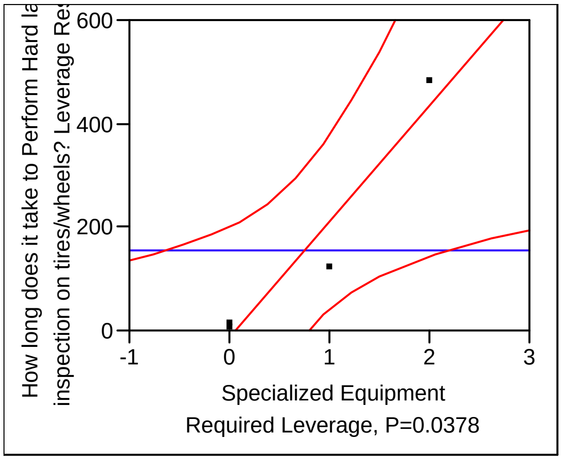
Summary of Fit

RSquare	0.925849
RSquare Adj	0.888773
Root Mean Square Error	74.66592
Mean of Response	153.75
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-15	50.33975	-0.30	0.7938
Specialized Equipment Required	225	45.02525	5.00	0.0378

Leverage Plot



Prediction Expression:

Time to perform a hard landing inspection = (-15) + Choose 0 (if no Specialized Equipment) OR 225 (if Specialized Equipment is required)

Model Analysis

With an r^2 value of 0.923, this model explains approximately 92 percent of the variation when used to perform a hard landing inspection given is any specialized equipment is required. Furthermore, a p-value of 0.038 suggests that approximately 94 percent of the time, this model will explain the parametric relationship between the time it takes to perform a hard landing inspection and whether or not specialized equipment is necessary to complete the task.

Because this model has a negative β_0 (intercept) value, it must be assumed that the corresponding number of interfaces which must be interrogated during this task has to be greater than or equal to one. Otherwise, if there was a method to perform a hard landing inspection without any specialized equipment, the time would be predicted to be less than zero, which is not practical.

<u>Question 37.</u> How long does it take to R2 Fuel Pump?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to R2 Fuel Pump?	240	60	240	360
Weight (lbs) of component	8	7	5	15
Size (volume-cu in) of component	603	603	50.2	603
# of access panels needing removed	1	1	2	5
Number of GSE items	1	1	0	2
Multiple Techs required-(# of)	2	1	2	2

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
141	Pumps and fuel system	Maintenance

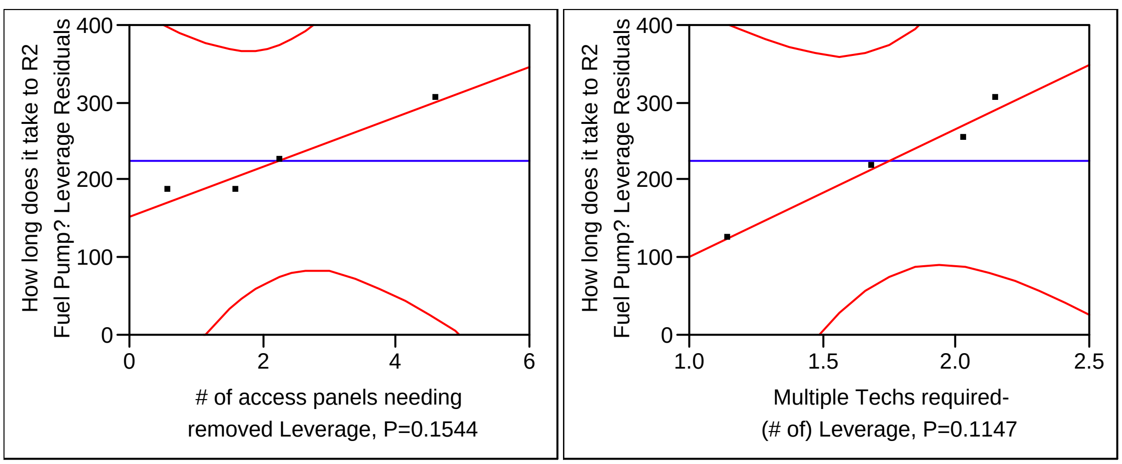
Summary of Fit

RSquare	0.987934
RSquare Adj	0.963801
Root Mean Square Error	23.53394
Mean of Response	225
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-138.4615	49.27882	-2.81	0.2177
# of access panels needing removed	32.307692	7.994081	4.04	0.1544
Multiple Techs required-(# of)	166.15385	30.2651	5.49	0.1147
COMPLETE MODEL			F-STAT	0.1098

Leverage Plot



Prediction Expression:

Time to remove and replace a fuel pump = (-138.4615) + 32.307692*number of access panels needing removed + 166.15385*Number of technicians required

Model Analysis

With an r^2 value of 0.988, this model explains approximately 99 percent of the variation when used to predict the time it takes to remove and replace a fuel pump given the number of access panels which must be removed to gain access to the part and the number of technicians required. Furthermore, a F-statistic of 0.110 suggests that

approximately 89 percent of the time, this model will explain the parametric relationship between the time it takes to remove and replace a fuel pump given the number of access panels needing removed and the number of technicians required.

Because this model has a negative β_0 (intercept) value, it must be assumed that the corresponding prediction estimate of the number of access panels and number of technicians required has to be greater than or equal to 138.4615. Otherwise, the overall time predicted would be less than zero, which of course, is not practical.

<u>Question 38</u>. How long does it take to R2 Batteries?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to R2 Batteries?	75	15	30	60
Weight (lbs) of component	20	5	100	25
Size (volume-cu in) of component	128	120	1728	1728
# of access panels needing removed	1	0	0	2
Number of GSE items	1	0	0	1
Multiple Techs required-(# of)	2	1	1	2

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
103	Replace Batteries	Maintenance

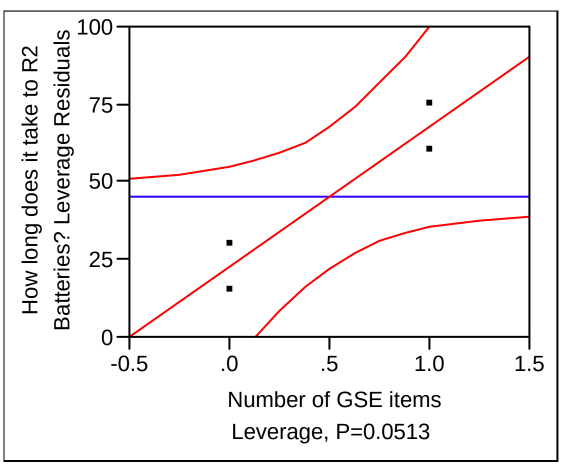
Summary of Fit

RSquare	0.9
RSquare Adj	0.85
Root Mean Square Error	10.6066
Mean of Response	45
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	22.5	7.5	3.00	0.0955
Number of GSE items	45	10.6066	4.24	0.0513

Leverage Plot



Prediction Expression:

Time to remove and replace batteries = 22.5 + 45*Number of GSE items

Model Analysis

With an r^2 value of 0.900, this model explains approximately 90 percent of the variation when used to predict the time it takes to remove and replace batteries given the number of GSE items required. Furthermore, a p-value of 0.051 suggests that approximately 95 percent of the time, this model will explain the parametric relationship between the time it takes to remove and replace batteries and the number of GSE items required.

<u>Question 39</u>. How long does it take to R2 Engine?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to R2 Engine-Main?	615	675	570	570
Weight (lbs) of component	3,500	8,000	5600	4,000
Size (volume-cu in) of component	167000	1528300	502400	332000
# of access panels needing removed	1	2	2	0
Number of GSE items	2	4	2	2
Multiple Techs required-(# of)	4	4	4	3

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
123	Remove Motor	Maintenance

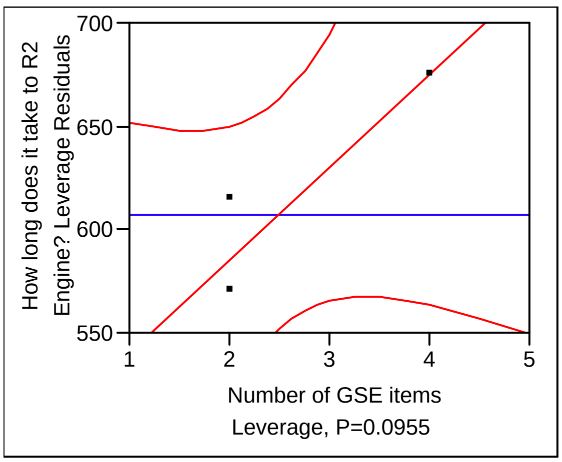
Summary of Fit

RSquare	0.818182
RSquare Adj	0.727273
Root Mean Square Error	25.98076
Mean of Response	607.5
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	495	39.68627	12.47	0.0064
Number of GSE items	45	15	3.00	0.0955

Leverage Plot



Prediction Expression:

Time to remove and replace an engine = 495 + 45*Number of GSE items required

Model Analysis

With an r^2 value of 0.818, this model explains approximately 81 percent of the variation when used to predict the time it takes to remove and replace an engine given the number of GSE items required. Furthermore, a p-value of 0.096 suggests that approximately 90 percent of the time, this model will explain the parametric relationship between removing and replacing an engine and the required number of GSE items needed to complete the task.

Question 90. **How long does it take to prepare a/c for transport (towing)?**

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to prepare a/c for transport (towing)?	10	30	10	15
Multiple Techs required-(# of)	7	3	6	3
Number of GSE items	2	1	2	2
Weight (lbs) of component / Spt Equip	0	0	0	0
Internal Access? (1=Yes, 0=No)	0	1	0	1
Lifting Required? (1=Yes, 0=No)	0	0	0	1

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
60	Transport preparations	Integration

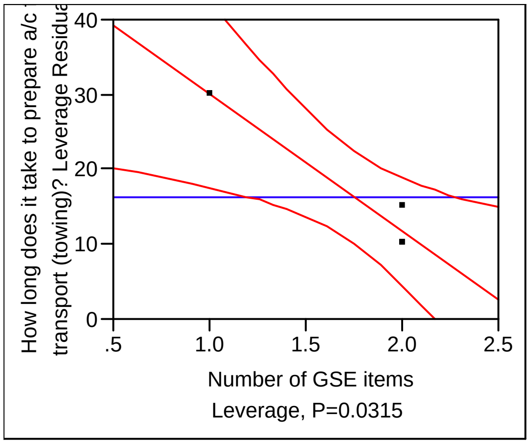
Summary of Fit

RSquare	0.937984
RSquare Adj	0.906977
Root Mean Square Error	2.886751
Mean of Response	16.25
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	48.333333	6.009252	8.04	0.0151
Number of GSE items	-18.33333	3.333333	-5.50	0.0315

Leverage Plot



Prediction Expression:

Time to prepare vehicle for towing = 48.333333 + (-18.33333)*Number of GSE items required

Model Analysis

With an r^2 value of 0.940, this model explains approximately 94 percent of the variation when used to predict the time it takes to prepare a vehicle for towing given the number of GSE items required. Furthermore, a p-value of 0.032 suggests that approximately 97 percent of the time, this model will explain the parametric relationship between prepare vehicle for towing and the required number of GSE items needed to complete the task.

If this model is utilized, careful consideration should be taken due to the somewhat counter-intuitive nature of the negative correlation between prep time an ground support equipment items. Upon reviewing the source data it was noted that the completion time for the C-5 on this task is longer and requires less GSE items than the remaining airframes. Thus the data suggests it would take less time if more GSE items are needed.

Question 92. How long does it take to Attach Tow Tug to a/c?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to Attach Tow Tug to a/c?	2	10	10	5
Multiple Techs required-(# of)	2	3	2	3
Number of GSE items	2	2	1	2
Weight (lbs) of component / Spt Equip	0	50	50	30
Internal Access? (1=Yes, 0=No)	0	0	0	1
Lifting Required? (1=Yes, 0=No)	0	0	0	1

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
169	Attach Tow Tug to RMLV	Post-Flight

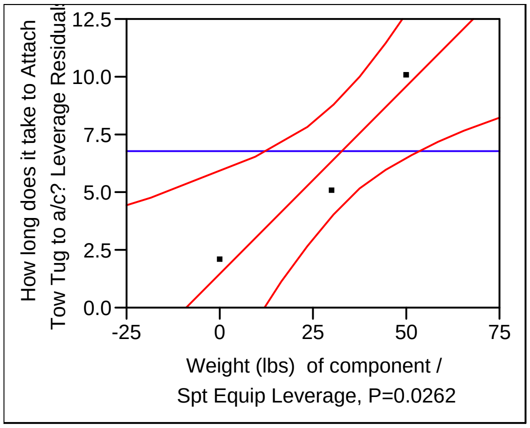
Summary of Fit

RSquare	0.94828
RSquare Adj	0.92242
Root Mean Square Error	1.099525
Mean of Response	6.75
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.4626866	1.031796	1.42	0.2920
Weight (lbs) of component / Spt Equip	0.1626866	0.026866	6.06	0.0262

Leverage Plot



Prediction Expression:

Time to attach a tow tug to an aircraft = 1.4626866 + 0.1626866*weight of support equipment

Model Analysis

With an r^2 value of 0.948, this model explains approximately 95 percent of the variation when used to predict the time it takes attach a tow tug to an aircraft given the weight of support equipment required. Furthermore, a p-value of 0.026 suggests that approximately 97 percent of the time, this model will explain the parametric relationship between attaching a tow tug to an aircraft and the weight of support equipment used in connecting the tow tug. This relationship is specifically due to the required lifting of the tow bar when hooking up the tow tug to the aircraft.

Question 94. How long does it take to make Final Tow Preps?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to make Final Tow Preps?	5	10	5	5
Multiple Techs required-(# of)	2	6	2	3
Number of GSE items	0	0	0	0
Weight (lbs) of component / Spt Equip	0	0	0	0
Internal Access? (1=Yes, 0=No)	1	0	1	1
Lifting Required? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
155	Final Tow Preps	Post-Flight

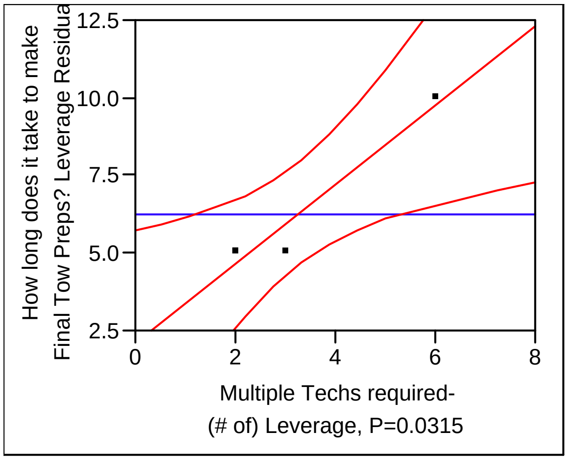
Summary of Fit

RSquare	0.937984
RSquare Adj	0.906977
Root Mean Square Error	0.762493
Mean of Response	6.25
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.0930233	0.846524	2.47	0.1320
Multiple Techs required-(# of)	1.2790698	0.232558	5.50	0.0315

Leverage Plot



Prediction Expression:

Time make final tow preparations = 2.0930233 + 1.2790698*Number of technicians required

Model Analysis

With an r^2 value of 0.938 this model explains approximately 94 percent of the variation when used to predict the time it takes to make final tow preparations given the number of maintenance technicians required. Furthermore, a p-value of 0.032 suggests that approximately 97 percent of the time, this model will explain the parametric relationship between the time it takes to make final tow preparations given the number of maintenance technicians required to complete the task.

<u>Question 95.</u> How long does it take to TOW Aircraft to an open pad?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to TOW Aircraft to an open pad?	10	20	15	10
Multiple Techs required-(# of)	7	6	4	3
Number of GSE items	2	2	2	2
MAX Weight (lbs) of A/C	336,500	800000	322500	37500
Internal Access? (1=Yes, 0=No)	1	1	0	1
Lifting Required? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
6	Move vehicle to launch pad	Integration
62	Transport vehicle to pad	Integration
156	TOW RMLV	Post-Flight

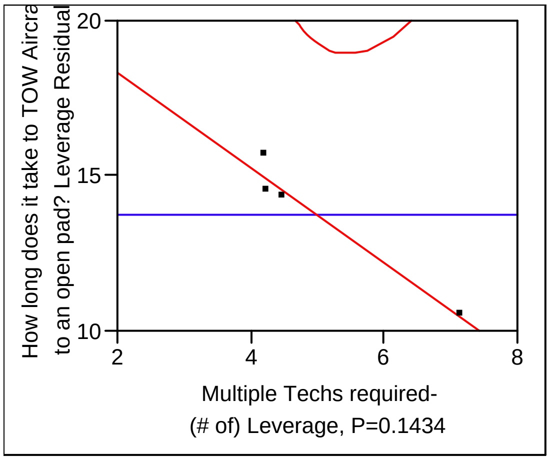
Summary of Fit

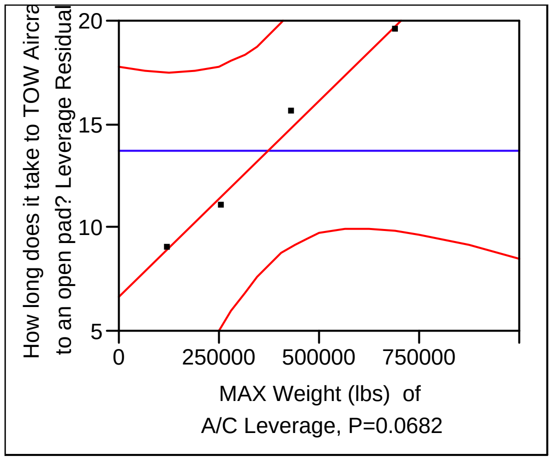
RSquare	0.988985
RSquare Adj	0.966956
Root Mean Square Error	0.870203
Mean of Response	13.75
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	14.344611	1.480938	9.69	0.0655
Multiple Techs required-(# of)	-1.534074	0.351517	-4.36	0.1434
MAX Weight (lbs) of A/C	0.000018913	2.034e-6	9.30	0.0682
COMPLETE MODEL			F-STAT	0.1050

Leverage Plot





Prediction Expression:

Time to tow aircraft to an open pad = 14.344611 + (-1.534074)*Number of technicians required + 0.000018913*aircraft weight

Model Analysis

With an r^2 value of 0.989 this model explains approximately 99 percent of the variation when used to predict the time it takes to tow aircraft to an open pad given the number of maintenance technicians required and the weight of the aircraft. Furthermore,

a p-value of 0.105 suggests that approximately 89 percent of the time, this model will explain the parametric relationship between the time it takes to tow an aircraft to an open pad given the number of maintenance technicians required and the weight of the aircraft.

<u>Question 96.</u> How long does it take to TOW Aircraft into a maintenance bay?

Source Data:

	B-2	C-5	KC-135	F-16
How long does it take to TOW Aircraft into a maintenance bay?	20	50	45	15
Multiple Techs required-(# of)	7	14	6	6
Number of GSE items	2	2	2	2
MAX Weight (lbs) of A/C	336500	800000	322500	37500
Internal Access? (1=Yes, 0=No)	1	1	0	1
Lifting Required? (1=Yes, 0=No)	0	0	0	0

Applicable Arena Processes :

Arena Process #	Process Description	Main Operation
7	Move vehicle to integration facility	Integration
2	Transport to Maintenance Bay	Maintenance
156	TOW RMLV	Post-Flight

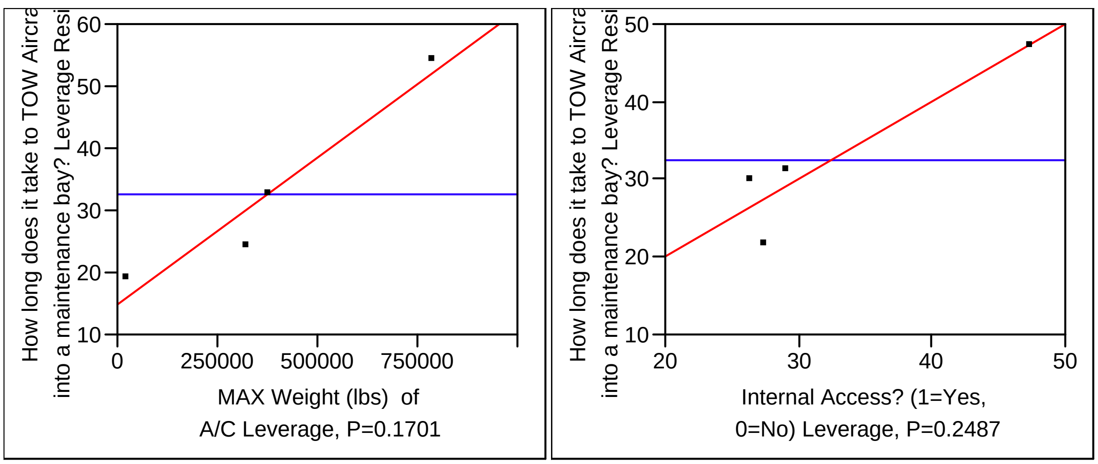
Summary of Fit

RSquare	0.945978
RSquare Adj	0.837934
Root Mean Square Error	7.068974
Mean of Response	32.5
Observations (or Sum Wgts)	4

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	29.674104	8.220427	3.61	0.1720
MAX Weight (lbs) of A/C	0.00004752	0.000013	3.65	0.1701
Internal Access? (1=Yes, 0=No)	-19.93778	8.211528	-2.43	0.2487
COMPLETE MODEL			F-STAT	0.2324

Leverage Plots



Prediction Expression:

Time to tow an aircraft into a maintenance bay = 29.674104 + 0.00004752*weight of aircraft + Choose 0 (if no Internal Access) OR -19.93778 (if Internal Access is required)

Model Analysis

With an r^2 value of 0.946, this model explains approximately 95 percent of the variation when used to predict the time it takes to tow an aircraft into a maintenance bay given whether or not internal access is required or not and the weight of aircraft.

Furthermore, a F-statistic of 0.232 suggests that approximately 77 percent of the time that this model will correctly identify the parametric relationship between the time it takes to tow an aircraft into a maintenance bay given the weight of aircraft and the possible requirement of internal access.

Regression Limitations

Many of the formulated models returned results which would lack fidelity if precise correlations were needed. Some analyses returned low r-squared values while others lacked significance due to high p-values. Additionally, the required testing of the assumptions of regression modeling were not able to be conducted due to the small sample size of only four aircraft. This limitation prevented the testing for outliers as well as the testing of model residuals for normality. Therefore, within the context of this research using only four aircraft; the results form a baseline for future research.

Discarded Models

The following is a list of data collection questions and associated MILEPOST processes which were unable to be analyzed due to data quantity not being sufficient (QNS) or the regression results displayed unacceptably poor correlation or totally lacked any significance (NO SIGNIFICANCE):

3 – Purge Tanks—DATA QNS

Arena Processes:		
147	Initiate Purge and Monitor	Post-Flight

4 – Vent tanks – DATA QNS

Arena Processes:		
175	LOX Safing	Post-Flight
158	Tank Vent RMLVME	Post-Flight

5 – Charge Batteries – DATA QNS

Arena Processes:		
104	Charge Batteries	Maintenance

10--Grounding procedures-- NO SIGNIFICANCE

Arena Processes:		
4	Grounding procedures	Maintenance

12 – Place New Engine on Stand – DATA QNS

Arena Processes:		
124	place new motor and stand	Maintenance

13 – Position Maintenance Stand – NO SIGNIFICANCE

Arena Processes:		
98	Position Maintenance stands	Maintenance

23 – Position Ground Crew – NO SIGNIFICANCE

Arena Processes:		
176	Ground Crew and GSE moved into position	Post-Flight

24 – Ground Crew Receive Safety Assessment – DATA QNS

Arena Processes:		
173	Ground Crew Receives Safety Self Assessment	Post-Flight

25 – Safe INS Recorder – DATA QNS

Arena Processes:		
165	INS Recorder Safing	Post-Flight

28 – Safe Propulsion System (engine) – DATA QNS

Arena Processes:		
159	Main Propulsion System Configuration	Post-Flight

29 – Interrogate on-board system reporter – DATA QNS

Arena Processes:		
97	Interrogate Maintenance Reporter	Maintenance
152	Monitor On board Systems	Post-Flight

34. R2 Engine Wire Harness – NO SIGNIFICANCE

Arena Processes:		
126	Elect Conn motor	Maintenance

40 – Install/Load Ordnance – DATA QNS

Arena Processes:		
81	Install arm ordnance	Integration
59	Install ordnance off pad	Integration

41 – Unload Ordnance – DATA QNS

Arena Processes:		
168	Load and Remove External Stores	Post-Flight

42 –Return Ordnance – DATA QNS

Arena Processes:		
167	Separate External Stores	Post-Flight

91 – Position Hookup Tug – NO SIGNIFICANCE

Arena Processes:		
154	Position Hookup Tug	Post-Flight

93 –Check Tow Tug Connections – DATA QNS

Arena Processes:		
170	Check Tow Tug Connections	Post-Flight

99 – Configure for Handover to Ground Control Techs– DATA QNS

Arena Processes:		
149	Configure for Handover to Spaceport Ground Control	Post-Flight

MISCELLANEOUS:
999 – Replace Individual Tile/TPS blanket – DATA QNS (B-2 only data source)

Arena Processes:		
132	Tile and Blanket R2	Maintenance

Experimental Design Results

Determining Experimental Factors and Levels

In order to determine if the factors identified in the regression analysis which displayed parametric relationships with task times influence RMLV design decisions, an experiment was designed and conducted. According to McClave, et al., an experiment is

said to be “designed” if the specifications of the treatments and method of obtaining response values are controlled by the analyst (McClave, et al., 2005).

During the experimental design of this study, the author selected the most frequently determined factors resulting from the regression analysis. Thus, the following factors were used in the experiment: number of technicians, fuel volume, aircraft weight, and number of GSE items. Furthermore, two levels were used for each of these factors; a high level and a low level. To incorporate the testing of different design decisions, B-2 data was used for the high level factors and F-16 data was used for the low. Table 4 represents the full factorial design used in this experiment.

Table 4: Two Level Experimental Design using B-2 and F-16 Data

	Factor and Level			
Model #	**# of Techs**	**Fuel Vol**	**A/C Wt**	**# of GSE**
1	F-16	F-16	F-16	F-16
2	B-2	F-16	F-16	F-16
3	B-2	B-2	F-16	F-16
4	B-2	F-16	B-2	F-16
5	B-2	F-16	F-16	B-2
6	F-16	B-2	F-16	F-16
7	F-16	B-2	B-2	F-16
8	F-16	B-2	F-16	B-2
9	F-16	F-16	B-2	F-16
10	F-16	F-16	B-2	B-2
11	B-2	B-2	B-2	F-16
12	F-16	B-2	B-2	B-2
13	B-2	F-16	B-2	B-2
14	B-2	B-2	F-16	B-2
15	B-2	B-2	B-2	B-2
16	F-16	F-16	F-16	B-2

For each of the 16 models, the most likely values of all MILEPOST processes affected by the factors used in this experiment were calculated using either B-2 or F-16 data according to the design outlined in Table 4. To accomplish this calculation, the

prediction estimates determined during the regression analyses were used for each of the affected processes. These values were determined to be the most likely times necessary to perform each respective process. Following previous MILEPOST research, triangular distributions were then calculated to determine the minimum and maximum values for each affected process. Minimum values were calculated by subtracting 10 percent from the most likely value, and maximum values were determined by adding 40 percent to the most likely value (Stiegelmeier, 2006). Finally, all 16 experimental design model process distributions were incorporated into the MILEPOST model for analysis.

Mimicking the RMLV entity path configurations used by Stiegelmeier during his experimental design comparison of a Preintegration versus No Preintegration decision, each of the 16 models were run to produce five replications each (Stiegelmeier, 2006). The MILEPOST regeneration times for each RMLV model configuration were recorded and evaluated to determine the possibility of factor influence on total task time. Complete statistical output results for both design decisions can be found in Appendix G.

Hypothesis Testing Results

The following hypothesis testing was conducted on the results of the five replications of MILEPOST output times for both Preintegration and No Preintegration design decisions:

H_0: All 16 model regeneration times are equal

H_a: At least two of the 16 model regeneration times differ

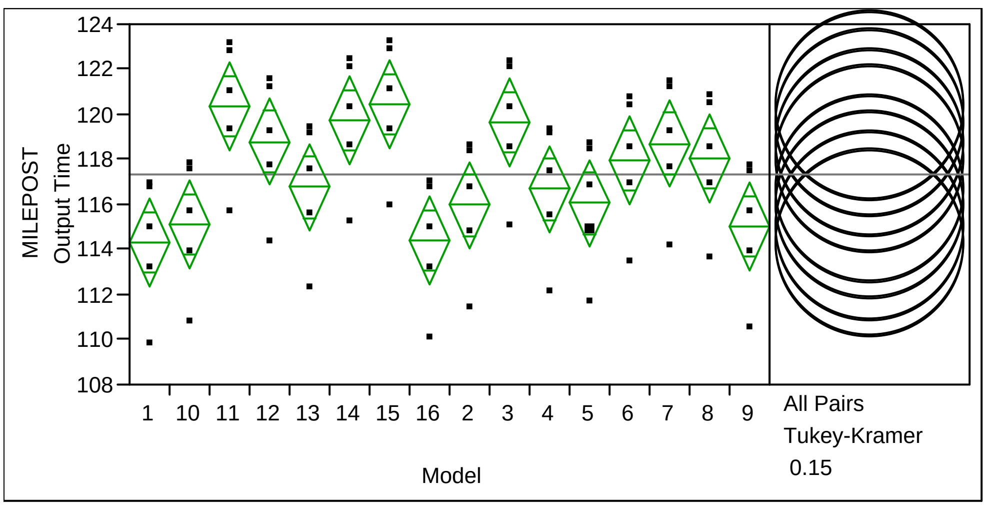
Preintegration Results:

Preintegration ANOVA:

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	15	335.00800	22.3339	2.5544	0.0048
Error	64	559.56283	8.7432		
C. Total	79	894.57083			

At a 0.1 level of significance, a p-value of 0.0048 resulted in the rejection of the null hypothesis. Thus, it was determined that at least two of the 16 models are statistically different from each other. Further testing was conducted utilizing the Tukey method for pairwise comparisons. The following results were obtained for the Preintegration models:

Graphical Comparison of 16 Preintegration Model Means:



Eighty-five percent confidence intervals were calculated for each model mean, with the resulting ranges being compared to each other. The results of this experimental design of Preintegration design decisions indicate statistical differences between the following models:

1. Model 1 and Model 11
2. Model 1 and Model 15
3. Model 16 and Model 11
4. Model 16 and Model 15

	Controls			
Model #	**Techs**	**Fuel**	**A/C Wt**	**GSE**
1	F-16	F-16	F-16	F-16
11	B-2	B-2	B-2	F-16
15	B-2	B-2	B-2	B-2
16	F-16	F-16	F-16	B-2

Further analysis reveals that model 1 is entirely comprised of F-16 data while model 15 is entirely comprised of B-2 data. Also, model 1 and model 16 share the same factor levels with the exception of the GSE factor. Likewise model 15 and model 11 share the same factor levels with the exception of the GSE factor. The statistical difference determined when comparing two models which contain completely opposite level factors indicate that the factors chosen for this experiment have an effect on the output of different design configurations.

Additionally, by examining the average model process times for each aircraft broken down by type of factor, it was determined that the B-2 processes which are affected by the number of technicians required, fuel volume, aircraft weight, or the number of ground support equipment items needed take approximately 46 percent longer to complete than similar F-16 processes. Further breaking down the processes and analyzing individually by influential factor reveal significant increases of time required for the B-2 processes involving number of technicians required, fuel volume, and aircraft

weight, but little significance due to ground support equipment items. Furthermore, a full factorial effects test was accomplished showing no significant interactions between individual factors.

	F-16	B-2	% Increase
Overall Avg	55.9543	81.825	46%
Breakdown:			
Techs	46.5402	53.8053	16%
Fuel	28.7272	89.7385	212%
A/C Wt	10.985	17.8486	62%
GSE	139.816	142.998	2%

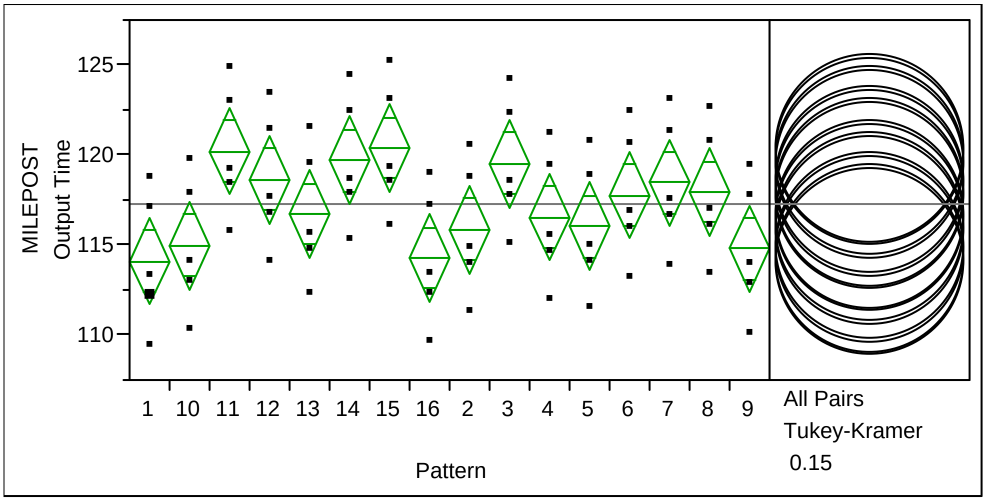
No Preintegration results:

No Preintegration ANOVA:

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Pattern	15	341.1383	22.7426	1.6505	0.0851
Error	64	881.8849	13.7795		
C. Total	79	1223.0233			

At a 0.1 level of significance, a p-value of 0.0851 resulted in the rejection of the null hypothesis. Thus, it was determined that at least two of the 16 models are statistically different from each other. Again, further testing was conducted utilizing the Tukey method for pairwise comparisons. The following results were obtained for the No Preintegration models:

Graphical Comparison of 16 No Preintegration Model Means:



Similarly, eighty-five percent confidence intervals were calculated for each model mean, with the resulting ranges being compared to each other. At this level, the results of this experimental design of No Preintegration did not indicate any statistical differences between any two set of model pairs. Although lacking significance, the greatest difference in means between model pairs is the same as identified in the Preintegration model. Thus, it can be determined with some greater confidence that the factors used in these experiments have significant influence on the outcome of certain RMLV design decisions.

Experimental Design Limitations

In developing the models for the experiment, the F-16 was selected to be used as the low factor while the B-2 was selected as the high value factor. Due to variations caused by additional factors which were not considered in this study, the F-16 data did not necessarily result in the shortest times and the B-2 data did not always correlate to the longest or largest time values. Other considerations such as system or operational "age"

of the aircraft may prove to have significant influence on task time than just overall aircraft size.

Summary

This chapter began with the construction of a notional WUC structure based on the MILEPOST processes. Next was a brief discussion of WUC data collection difficulties in REMIS. This was followed by the creation of parametric models using regression techniques and listings of model limitations and the presentation of some discarded models were provided. Finally, the testing of these models using an experimental design concluded this chapter.

V. Conclusions and Recommendations

Introduction

This chapter begins with a summary of the research which was conducted during this thesis and then identifies conclusions. The chapter concludes with a discussion of some suggestions for future research.

Research Summary

Parametric Relationships

Through the efforts of this research it has been possible to identify parametric relationships between MILEPOST regeneration process activity times and certain influential human factors. The parametric calculations determined through regression analysis were utilized during an experimental design test which incorporated factor based process distribution times into MILEPOST to determine the significance of several factors chosen by the author as having influence on maintenance times.

As a result of the determined parametric relationships, more robust maintenance data can be used within future MILEPOST model runs, thus adding fidelity and validity to the ongoing efforts within the RMLV program.

Categories of Maintenance and Factors

Additionally, this research identified and organized the MILEPOST discrete event simulation processes into five primary categories which maintenance tasks fall within. Also, the significant factors which affect maintenance processes were identified. Through the organization of the MILEPOST processes and identifying significant factors affecting those actions, statistical regression analysis was able to be employed. A

reference table listing the parametric relationships and each process prediction expression is presented in Appendix A.

Work Unit Code Table

During this research effort, a notional WUC structure was developed. Furthermore, verification was conducted by a REMIS Systems Analyst which confirmed that the MILEPOST processes as well as the constructed codes would easily be integrated into the Air Force maintenance database.

Research Limitations

Many of the formulated models returned results which would lack fidelity if precise correlations were needed. Due to the small sample size of only four aircraft, the required testing of the assumptions of regression modeling was not able to be conducted. This limitation prevented the testing for outliers as well as the testing of model residuals for normality. Therefore, within the context of this research using only four aircraft; the results form a baseline for future research.

Additionally, several processes within MILEPOST were not analyzed for relational links to factors due to a lack of space system data or insignificant results. For these processes, simple mean calculations were accomplished utilizing the imbedded triangular distribution times in Arena. These mean values can be compared to the average times calculated for the corresponding maintenance tasks using the data obtained from the four airframes used in this study. See Appendix A to compare means.

The results of the regression analyses or the mean calculations serve to accomplish the primary goal of this research: to improve the fidelity of the RMLV simulation model (MILEPOST) previously developed. By improving the accuracy and

precision of the simulation model, an increase in the fidelity and validity of the RMLV simulation concept is realized. As the priorities of our nation call out for an increase in the capabilities of spaced based systems, leaders in decision-making positions are better able to conduct more in-depth and accurate analyses using data similar to this research thus ensuring the most efficient spending of critical budget dollars.

Recommendations for Future Research

Further analysis of MILEPOST Integration Processes

Due to a lack of data available from Air Force and commercial space-based systems, many of the MILEPOST integration processes were excluded from this study. Further analysis in this area would complete this research effort in establishing parametric relationships for ALL simulation process modules.

To accomplish this, additional research would need to be conducted on existing Air Force space systems as well as other existing aircraft such as the F-22, C-17, and Commercial Aircraft. Additionally, further studies would involve a thorough collection of data, requiring site visits to Air Force bases and launch locations.

Parametric Relationships Beyond MILEPOST

Further analysis on maintenance tasks and times could be conducted to establish a more broad evaluation on the factors which affect maintenance and their impact on the task completion time. To accomplish this additional research, a query could be conducted within REMIS to identify ALL WUCs for ALL Air Force airframes identifying the Mean Time Between Failure and Mean Repair Times.

Evaluating the Mean Time Between Failure (MTBF) values will identify those components which display the lowest reliability rates, i.e., those components which break

most often. Studying the Mean Repair Times (MRT) would identify the components which take the longest to repair. Furthermore, employing similar methodologies as this research employed, a survey could be conducted on a much larger scale to include a large number of maintenance professionals across all of the airframes to identify which key factors affect the most common (MTBF) or most difficult (MRT) maintenance actions, as well as to what degree the factors affect those times.

RMLV Supply Chain Mapping

Additional research is needed to further establish a baseline supportability analysis of the RMLV concept. One area which is lacking is in the area of parts availability and supply/maintenance reliability. To accomplish this research a notional Supply Chain Map of a proposed RMLV could be completed.

Currently, most RMLV simulation models do not take into consideration the time for any supply delays. By evaluating the current space industry, supply distributors, unique components, and unique sole-source providers may be identified. Thus, it may be possible to identify potential part and supply shortfalls prior to the acquisition phase of the life cycle of the RMLV. This could potentially result in significant sustainment decisions. Furthermore, the creation and analysis of an Inventory Management model to include Depot level maintenance may benefit the RMLV design process in the future.

Appendix A: Process Means and Prediction Expressions

Process	Process Description	Arena Mean	A/C Mean	R^2	P-value	Prediction Expression
145	Forward Safety Assessments	13.2	23.0	0.999	0.001	Time to perform forward safety assessments = (-38.66667) + 49.333333*Number of technicians required
164	Aft Safety Assessments	13.2	23.0	0.999	0.001	Time to perform aft safety assessments = (-38.66667) + 49.333333*Number of technicians required
102	Flight Controls	33.0	36.3	0.998	0.001	Time to perform flight control checks = 8.3333333 + 55.833333*Number of interfaces interrogated
6	Move vehicle to launch pad	33.0	13.8	0.99	0.1	Time to tow aircraft to an open pad = 14.344611 + (-1.534074)*Number of technicians required + 0.000018913*aircraft weight
62	Transport vehicle to pad	33.0	13.8	0.99	0.1	Time to tow aircraft to an open pad = 14.344611 + (-1.534074)*Number of technicians required + 0.000018913*aircraft weight
156	TOW RMLV	60.0	13.8	0.99	0.1	Time to tow aircraft to an open pad = 14.344611 + (-1.534074)*Number of technicians required + 0.000018913*aircraft weight
111	Filters 1	99.0	71.3	0.99	0.0	Time to replace an engine filter = 217.5 + (-97.5)*Number of GSE items used
112	Filters 2	99.0	71.3	0.99	0.0	Time to replace an engine filter = 217.5 + (-97.5)*Number of GSE items used
141	Pumps and fuel system	132.0	225.0	0.99	0.1	Time to remove and replace a fuel pump = (-138.4615) + 32.307692*number of access panels needing removed + 166.15385*Number of technicians required
105	Battery testing	32.0	10.5	0.97	0.0	Time to perform a battery function check = 4 + Choose 0 (if no Specialized Equipment) OR 26 (if Specialized Equipment is required)
153	Install MPS and RMLV Protective Covers	66.0	20.0	0.97	0.0	Time to install protective covers = 14.545455 + 7.2727273*Number of GSE items
140	Engine Diagnostics	132.0	67.5	0.96	0.0	Time to perform engine diagnostics = 120 + Choose 0 (if no Specialized Equipment) OR (- 70) (if Specialized Equipment is required)
169	Attach Tow Tug to RMLV	5.5	6.8	0.95	0.0	Time to attach a tow tug to an aircraft = 1.4626866 + 0.1626866*weight of support equipment

2	Transport to Maintenance Bay	30.0	32.5	0.95	0.2	Time to tow an aircraft into a maintenance bay = 29.674104 + 0.00004752*weight of aircraft + Choose 0 (if no Internal Access) OR -19.93778 (if Internal Access is required)
7	Move vehicle to integration facility	16.5	32.5	0.95	0.2	Time to tow an aircraft into a maintenance bay = 29.674104 + 0.00004752*weight of aircraft + Choose 0 (if no Internal Access) OR -19.93778 (if Internal Access is required)
156	TOW RMLV	60.0	32.5	0.95	0.2	Time to tow an aircraft into a maintenance bay = 29.674104 + 0.00004752*weight of aircraft + Choose 0 (if no Internal Access) OR -19.93778 (if Internal Access is required)
127	Connection Test	66.0	165.0	0.94	0.2	Time to perform an Engine Connection Test = 38.571429 + 21.428571*Number of interfaces + Choose 0 (if no Specialized Equipment) OR 90 (if Specialized Equipment is required)
172	APU Shutdown	19.8	2.7	0.94	0.2	Time to shutdown an APU = (-2)+ 3.5*Number of technicians required
155	Final Tow Preps	33.0	6.3	0.94	0.0	Time make final tow preparations = 2.0930233 + 1.2790698*Number of technicians required
60	Transport preparations	132.0	16.3	0.94	0.0	Time to prepare vehicle for towing = 48.333333 + (-18.33333)*Number of GSE items required
99	Electrical Connections 2	10.7	2.5	0.93	0.0	Time to perform an electrical connection check = (-1.666667) + 3.3333333*Number of interfaces to interrogate
100	Upper Stage Electrical Connecting Point Testing	56.0	2.5	0.93	0.0	Time to perform an electrical connection check = (-1.666667) + 3.3333333*Number of interfaces to interrogate
117	Landing Gear and tires	190.0	153.8	0.93	0.0	Time to perform a hard landing inspection = (-15) + Choose 0 (if no Specialized Equipment) OR 225 (if Specialized Equipment is required)
109	hydraulic condition	32.0	26.0	0.92	0.3	Time to perform hydraulic fluid condition checks = (-2) + Choose 0 (if internal access is required) OR 38 (if additional analysis is required) + Choose 0 (if no additional analysis is required) OR 18 (if additional analysis is required)
103	Replace Batteries	99.0	45.0	0.90	0.1	Time to remove and replace batteries = 22.5 + 45*Number of GSE items

58	Load hypergolic fuel off pad	924.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
75	Load hypergolic fuel on pad	924.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
76	Fuel RP first stage	132.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
77	Fuel RP first stage 1	132.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
78	Fuel RP second stage	66.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
79	Fuel RP first stage 2	132.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
80	Fuel RP second stage 1	66.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
89	1st stage fuel chill and fill 2	66.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
90	2nd stage fuel chill and fill 2	33.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
92	1st stage fuel chill and fill 1	66.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
93	2nd stage fuel chill and fill 1	33.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
94	2nd stage fuel chill and fill	33.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
95	1st stage fuel chill and fill	66.0	101.3	0.89	0.1	Time to perform fueling operations = 25.850139 + 0.0004239* LBS Fluid/fuel volume
114	Engine Controls	132.0	105.0	0.85	0.1	Time to perform an engine controls check = (-90) + 60*Number of maintenance technicians
123	Remove Motor	132.0	607.5	0.82	0.1	Time to remove and replace an engine = 495 + 45*Number of GSE items required
110	Lubrication check	32.0	63.8	0.76	0.1	Time to perform a lubrication check = 45 + Choose 0 (if no additional analysis is required) OR 75 (if additional analysis is required)
113	LRU R2	99.0	56.3	0.70	0.2	Time to remove and replace a standard LRU = 22.5 + 67.5*Number of panels removed

143	Sensor Equipment	66.0	120.0	0.60	0.2	Time to perform sensor tests = 240 + Choose 0 (if no Internal Access) OR (-140) (if Internal Access is required)
150	Install Ground Lock Pins and Vent Plugs	13.2	12.5	0.60	0.2	Time to install ground lock pins and vent plugs = 25 + (-10)*Number of technicians required
142	Engine checkout	66.0	112.5	0.47	0.3	Time to complete an engine function check = (-150) + 70*Number of technicians required to perform this task
120	Connect motor stand	66.0	292.5	0.44	0.3	Time to connect an engine to a stand = 177.27273 + 35.454545*Number of Techs required
101	Avionics Testing	66.0	135.0	0.44	0.3	Time to perform an avionics function check = 60 + Choose 0 (if no Specialized Equipment) OR 100 (if Specialized Equipment is required)
83	1st stage LOX chill and fill	66.0	50.0	0.33	0.4	Time to perform liquid oxygen filling = 80 + (-20)* Number of Technicians
84	2nd stage LOX chill and fill	33.0	50.0	0.33	0.4	Time to perform liquid oxygen filling = 80 + (-20)* Number of Technicians
85	1st stage LOX chill and fill 1	66.0	50.0	0.33	0.4	Time to perform liquid oxygen filling = 80 + (-20)* Number of Technicians
86	2nd stage LOX chill and fill 1	33.0	50.0	0.33	0.4	Time to perform liquid oxygen filling = 80 + (-20)* Number of Technicians
87	1st stage LOX chill and fill 2	66.0	50.0	0.33	0.4	Time to perform liquid oxygen filling = 80 + (-20)* Number of Technicians
88	2nd stage LOX chill and fill 2	33.0	50.0	0.33	0.4	Time to perform liquid oxygen filling = 80 + (-20)* Number of Technicians
128	Disco stand and remove	66.0	97.5	0.33	0.4	Time to disconnect an engine stand = 70 + Choose 0 (if no Internal Access) OR 110 (if Internal Access is required)
130	Disco stand	32.0	97.5	0.33	0.4	Time to disconnect an engine stand = 70 + Choose 0 (if no Internal Access) OR 110 (if Internal Access is required)
166	Position External Store GSE	5.5	18.8	0.33	0.4	Time to position GSE = 0 + 15*Number of technicians required
4	Grounding procedures	20.0	3.8	NO SIG.	N/A	N/A
154	Position Hookup Tug	33.0	5.5	NO SIG.	N/A	N/A
176	Ground Crew and GSE moved into position	2.2	10.0	NO SIG.	N/A	N/A
98	Position Maintenance stands	62.0	62.5	NO SIG.	N/A	N/A
126	Elect Conn motor	66.0	135.0	NO SIG.	N/A	N/A
170	Check Tow Tug	5.5	2.7	DATA	N/A	N/A

	Connections			QNS		
165	INS Recorder Safing	16.5	5.5	DATA QNS	N/A	N/A
173	Ground Crew Receives Safety Self Assessment	2.2	5.5	DATA QNS	N/A	N/A
97	Interrogate Maintenance Reporter	10.7	10.0	DATA QNS	N/A	N/A
152	Monitor On board Systems	55.0	10.0	DATA QNS	N/A	N/A
149	Configure for Handover to Spaceport Ground Control	11.0	20.0	DATA QNS	N/A	N/A
159	Main Propulsion System Configuration	11.0	30.0	DATA QNS	N/A	N/A
167	Separate External Stores	44.0	30.0	DATA QNS	N/A	N/A
59	Install ordnance off pad	396.0	40.0	DATA QNS	N/A	N/A
81	Install arm ordnance	396.0	40.0	DATA QNS	N/A	N/A
168	Load and Remove External Stores	11.0	40.0	DATA QNS	N/A	N/A
158	Tank Vent RMLVME	11.0	45.0	DATA QNS	N/A	N/A
175	LOX Safing	1.1	45.0	DATA QNS	N/A	N/A
147	Initiate Purge and Monitor	61.4	60.0	DATA QNS	N/A	N/A
104	Charge Batteries	198.0	75.0	DATA QNS	N/A	N/A
124	place new motor and stand	66.0	75.0	DATA QNS	N/A	N/A
132	Tile and Blanket R2	280.0	1920.0	DATA QNS	N/A	N/A

Appendix B: MILEPOST Processes to Maintenance Category

Process #	Process Description	Maintenance Category
1	Connect to Stage1	Spt Function (Equip) / Pre-Repair / Prep Actions
2	Transport to Maintenance Bay	Spt Function (Equip) / Pre-Repair / Prep Actions
3	Position Stage1 in Maintenance Bay	Spt Function (Equip) / Pre-Repair / Prep Actions
4	Grounding procedures	Spt Function (Equip) / Pre-Repair / Prep Actions
5	Disconnect from Stage1	Spt Function (Equip) / Pre-Repair / Prep Actions
6	Move vehicle to launch pad	Spt Function (Equip) / Pre-Repair / Prep Actions
7	Move vehicle to integration facility	Spt Function (Equip) / Pre-Repair / Prep Actions
8	Attach handling fixture to payload	Spt Function (Equip) / Pre-Repair / Prep Actions
9	Align payload with second stage	Spt Function (Equip) / Pre-Repair / Prep Actions
10	Make mechanical connections	Spt Function (Equip) / Pre-Repair / Prep Actions
11	Make electrical connections	Spt Function (Equip) / Pre-Repair / Prep Actions
12	second stage and payload integration check	Inspections / Checks / Diagnosis / Troubleshooting
13	Attach handling fixture to HLV on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
14	Erect and position HLV on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
15	Attach handling fixture to 2nd stage payload on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
16	Lift and align 2nd stage payload on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
17	Make mechanical connections on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
18	Make electrical connections on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
19	Attach handling fixture to HLV on pad no preint	Spt Function (Equip) / Pre-Repair / Prep Actions
20	Erect and position HLV on pad no preint	Spt Function (Equip) / Pre-Repair / Prep Actions
21	Attach handling fixture to 2nd stage on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
22	Erect and position 2nd stage on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
23	Make mechanical connections on pad no preint	Spt Function (Equip) / Pre-Repair / Prep Actions
24	Make electrical connections on pad no preint	Spt Function (Equip) / Pre-Repair / Prep Actions
25	1st 2nd stage integration check on pad	Inspections / Checks / Diagnosis / Troubleshooting
26	Attach payload handling equipment on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
27	Lift and align payload on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
28	Make mechanical connections payload on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
29	Make electrical connections payload on pad	Spt Function (Equip) / Pre-Repair / Prep Actions
30	Entire vehicle integration check on pad	Inspections / Checks / Diagnosis / Troubleshooting
31	Attach handling fixture to HLV off pad	Spt Function (Equip) / Pre-Repair / Prep Actions

32	Erect and position HLV on MLP off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
33	Attach handling fixture to 2nd stage payload off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
34	Erect and position 2nd stage payload off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
35	Make mechanical connections off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
36	Make electrical connections off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
37	Attach handling equipment to 2nd stage payload off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
38	Position align 2nd stage payload off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
39	Make mechanical connections off pad 1	Spt Function (Equip) / Pre-Repair / Prep Actions
40	Make electric connections off pad 1	Spt Function (Equip) / Pre-Repair / Prep Actions
41	Attach payload handling equipment off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
42	Lift or position and align payload off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
43	Make payload mechanical connections off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
44	Make payload electrical connections off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
45	Attach handling fixture to HLV off pad 1	Spt Function (Equip) / Pre-Repair / Prep Actions
46	Erect and position HLV on MLP off pad 1	Spt Function (Equip) / Pre-Repair / Prep Actions
47	Attach handling fixture to 2nd stage off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
48	Erect and position 2nd stage off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
49	Make mechanical connections off pad 2	Spt Function (Equip) / Pre-Repair / Prep Actions
50	Make electrical connections off pad 2	Spt Function (Equip) / Pre-Repair / Prep Actions
51	1st 2nd stage integration check off pad	Inspections / Checks / Diagnosis / Troubleshooting
52	Attach handling equipment to 2nd stage off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
53	Position and align 2nd stage off pad	Spt Function (Equip) / Pre-Repair / Prep Actions
54	Make mechanical connections off pad 3	Spt Function (Equip) / Pre-Repair / Prep Actions
55	Make electrical connections off pad 3	Spt Function (Equip) / Pre-Repair / Prep Actions
56	1st and 2nd stage integration check off pad 1	Inspections / Checks / Diagnosis / Troubleshooting
57	Entire vehicle integration check off pad	Inspections / Checks / Diagnosis / Troubleshooting
58	Load hypergolic fuel off pad	Fluids / Hazards / Lubrication Actions
59	Install ordnance off pad	Fluids / Hazards / Lubrication Actions
60	Transport preparations	Spt Function (Equip) / Pre-Repair / Prep Actions
61	Attach transporter	Spt Function (Equip) / Pre-Repair / Prep Actions
62	Transport vehicle to pad	Spt Function (Equip) / Pre-Repair / Prep Actions

63	Position MLP on launch pad	Spt Function (Equip) / Pre-Repair / Prep Actions
64	Attach the erecting mechanism	Spt Function (Equip) / Pre-Repair / Prep Actions
65	Erect vehicle and secure to launch platform	Spt Function (Equip) / Pre-Repair / Prep Actions
66	Attach payload handling equipment on pad 1	Spt Function (Equip) / Pre-Repair / Prep Actions
67	Lift and align payload on pad 1	Spt Function (Equip) / Pre-Repair / Prep Actions
68	Make mechanical connections payload on pad 1	Spt Function (Equip) / Pre-Repair / Prep Actions
69	Make electrical connections payload on pad 1	Spt Function (Equip) / Pre-Repair / Prep Actions
70	Entire vehicle integration check on pad 1	Inspections / Checks / Diagnosis / Troubleshooting
71	Propellant connections	Spt Function (Equip) / Pre-Repair / Prep Actions
72	Umbilical leak check	Inspections / Checks / Diagnosis / Troubleshooting
73	Electrical and □enja connections	Spt Function (Equip) / Pre-Repair / Prep Actions
74	Verify electrical and □enja connectivity	Inspections / Checks / Diagnosis / Troubleshooting
75	Load hypergolic fuel on pad	Fluids / Hazards / Lubrication Actions
76	Fuel RP first stage	Fluids / Hazards / Lubrication Actions
77	Fuel RP first stage 1	Fluids / Hazards / Lubrication Actions
78	Fuel RP second stage	Fluids / Hazards / Lubrication Actions
79	Fuel RP first stage 2	Fluids / Hazards / Lubrication Actions
80	Fuel RP second stage 1	Fluids / Hazards / Lubrication Actions
81	Install arm ordnance	Fluids / Hazards / Lubrication Actions
82	Final TPS or other inspection	Inspections / Checks / Diagnosis / Troubleshooting
83	1st stage LOX chill and fill	Fluids / Hazards / Lubrication Actions
84	2nd stage LOX chill and fill	Fluids / Hazards / Lubrication Actions
85	1st stage LOX chill and fill 1	Fluids / Hazards / Lubrication Actions
86	2nd stage LOX chill and fill 1	Fluids / Hazards / Lubrication Actions
87	1st stage LOX chill and fill 2	Fluids / Hazards / Lubrication Actions
88	2nd stage LOX chill and fill 2	Fluids / Hazards / Lubrication Actions
89	1st stage fuel chill and fill 2	Fluids / Hazards / Lubrication Actions
90	2nd stage fuel chill and fill 2	Fluids / Hazards / Lubrication Actions
91	Terminal countdown	N/A
92	1st stage fuel chill and fill 1	Fluids / Hazards / Lubrication Actions
93	2nd stage fuel chill and fill 1	Fluids / Hazards / Lubrication Actions
94	2nd stage fuel chill and fill	Fluids / Hazards / Lubrication Actions
95	1st stage fuel chill and fill	Fluids / Hazards / Lubrication Actions
96	Launch	N/A
97	Interrogate Maintenance Reporter	Inspections / Checks / Diagnosis / Troubleshooting
98	Position Maintenance stands	Spt Function (Equip) / Pre-Repair / Prep Actions
99	Electrical Connections 2	Inspections / Checks / Diagnosis / Troubleshooting
100	Upper Stage Electrical Connecting Point Testing	Inspections / Checks / Diagnosis / Troubleshooting

101	Avionics Testing	Inspections / Checks / Diagnosis / Troubleshooting
102	Flight Controls	Inspections / Checks / Diagnosis / Troubleshooting
103	Replace Batteries	Remove / Replace (Main Component)
104	Charge Batteries	Spt Function (Equip) / Pre-Repair / Prep Actions
105	Battery testing	Inspections / Checks / Diagnosis / Troubleshooting
106	Stage2 Mech Conn	Spt Function (Equip) / Pre-Repair / Prep Actions
107	Stage2 Area Hardware	Spt Function (Equip) / Pre-Repair / Prep Actions
108	Buffer Plug R2	Remove / Replace (Main Component)
109	hydraulic condition	Inspections / Checks / Diagnosis / Troubleshooting
110	Lubrication check	Inspections / Checks / Diagnosis / Troubleshooting
111	Filters 1	Remove / Replace (Main Component)
112	Filters 2	Remove / Replace (Main Component)
113	LRU R2	Remove / Replace (Main Component)
114	Engine Controls	Inspections / Checks / Diagnosis / Troubleshooting
115	Nozzles	Spt Function (Equip) / Pre-Repair / Prep Actions
116	Linkage	Spt Function (Equip) / Pre-Repair / Prep Actions
117	Landing Gear and tires	Inspections / Checks / Diagnosis / Troubleshooting
118	Preplanned maintenance	Spt Function (Equip) / Pre-Repair / Prep Actions
119	TCTO actions	Inspections / Checks / Diagnosis / Troubleshooting
120	Connect motor stand	Spt Function (Equip) / Pre-Repair / Prep Actions
121	Dico Elect from Stage1	Spt Function (Equip) / Pre-Repair / Prep Actions
122	Disco Mech from Stage1	Spt Function (Equip) / Pre-Repair / Prep Actions
123	Remove Motor	Remove / Replace (Main Component)
124	place new motor and stand	Spt Function (Equip) / Pre-Repair / Prep Actions
125	mech connect motor to Stage1	Adjustments / Calibrations / Post-Repair QC
126	Elect Conn motor	Remove / Replace (Main Component)
127	Connection Test	Inspections / Checks / Diagnosis / Troubleshooting
128	Disco stand and remove	Spt Function (Equip) / Pre-Repair / Prep Actions
129	Drag Chute	Remove / Replace (Main Component)
130	Disco stand	Spt Function (Equip) / Pre-Repair / Prep Actions
131	Visual Check TPS	Inspections / Checks / Diagnosis / Troubleshooting
132	Tile and Blanket R2	Remove / Replace (Main Component)
133	Thermal Barrier Repair	Remove/Replace (Other)
134	Gap Filler R2	Remove/Replace (Other)
135	Sealant Application	Remove/Replace (Other)
136	Curing	Adjustments / Calibrations / Post-Repair QC
137	Recheck TPS	Adjustments / Calibrations / Post-Repair QC
138	HLV systems check	Inspections / Checks / Diagnosis / Troubleshooting

139	Waterproof TPS	Adjustments / Calibrations / Post-Repair QC
140	Engine Diagnostics	Inspections / Checks / Diagnosis / Troubleshooting
141	Pumps and fuel system	Remove / Replace (Main Component)
142	Engine checkout	Inspections / Checks / Diagnosis / Troubleshooting
143	SensorEquipment	Inspections / Checks / Diagnosis / Troubleshooting
144	Reaction Jet Drive and Drag Chute Pyro Safing	Fluids / Hazards / Lubrication Actions
145	Forward Safety Assessments	Inspections / Checks / Diagnosis / Troubleshooting
146	Connect Purge and Inerting GSE Umbilicals and Monitor	Spt Function (Equip) / Pre-Repair / Prep Actions
147	Initiate Purge and Monitor	Fluids / Hazards / Lubrication Actions
148	Connect Coolant GSE Umbilicals	Spt Function (Equip) / Pre-Repair / Prep Actions
149	Configure for Handover to Spaceport Ground Control	Spt Function (Equip) / Pre-Repair / Prep Actions
150	Install Ground Lock Pins and Vent Plugs	Spt Function (Equip) / Pre-Repair / Prep Actions
151	Initiate Ground Cooling	Fluids / Hazards / Lubrication Actions
152	Monitor On board Systems	Inspections / Checks / Diagnosis / Troubleshooting
153	Install MPS and RMLV Protective Covers	Spt Function (Equip) / Pre-Repair / Prep Actions
154	Position Hookup Tug	Spt Function (Equip) / Pre-Repair / Prep Actions
155	Final Tow Preps	Spt Function (Equip) / Pre-Repair / Prep Actions
156	TOW RMLV	Spt Function (Equip) / Pre-Repair / Prep Actions
157	OMS RCS System Safing	Spt Function (Equip) / Pre-Repair / Prep Actions
158	Tank Vent RMLVME	Fluids / Hazards / Lubrication Actions
159	Main Propulsion System Configuration	Spt Function (Equip) / Pre-Repair / Prep Actions
160	Hydrozine Circulation Pump Safing	Fluids / Hazards / Lubrication Actions
161	Stow Air Data Probes	Spt Function (Equip) / Pre-Repair / Prep Actions
162	MX Delay for Safety Downgrade	Fluids / Hazards / Lubrication Actions
163	MX Delay Safety for Haz Gas	Fluids / Hazards / Lubrication Actions
164	Aft Safety Assessments	Inspections / Checks / Diagnosis / Troubleshooting
165	INS Recorder Safing	Spt Function (Equip) / Pre-Repair / Prep Actions
166	Position External Store GSE	Fluids / Hazards / Lubrication Actions
167	Separate External Stores	Fluids / Hazards / Lubrication Actions
168	Load and Remove External Stores	Fluids / Hazards / Lubrication Actions
169	Attach Tow Tug to RMLV	Spt Function (Equip) / Pre-Repair / Prep Actions
170	Check Tow Tug Connections	Inspections / Checks / Diagnosis / Troubleshooting
171	RMLV Taxi to Recovery Apron	Spt Function (Equip) / Pre-Repair / Prep Actions
172	APU Shutdown	Spt Function (Equip) / Pre-Repair / Prep Actions
173	Ground Crew Receives Safety Self Assessment	Inspections / Checks / Diagnosis / Troubleshooting
174	Superficial TPS and debris	Inspections / Checks / Diagnosis /

	Inspection	Troubleshooting
175	LOX Safing	Fluids / Hazards / Lubrication Actions
176	Ground Crew and GSE moved into position	Spt Function (Equip) / Pre-Repair / Prep Actions

Appendix C: Data Collection Form

Aircraft Type:_________		
#	**QUESTIONS**	**Time? / Factor Data?**
1	How long does it take to **Fill (Load) Aircraft fuel tank(s) (considered empty)?**	
	Fluid/fuel volume	
	Number of GSE items	
	Multiple Techs required-(# of)	
	Multiple AFSCs required-(# of)	
	Internal or External Access	
2	How long does it take to **Fill (Load) Aircraft LOX tank(s) (considered empty)?**	
	Fluid/fuel volume	
	Number of GSE items	
	Multiple Techs required-(# of)	
	Multiple AFSCs required-(# of)	
	Internal or External Access	
3	How long does it take to **Purge Aircraft fuel tank(s)?**	
	Fluid/fuel volume	
	Number of GSE items	
	Multiple Techs required-(# of)	
	Multiple AFSCs required-(# of)	
	Internal or External Access	
4	How long does it take to **Vent Aircraft fuel tank(s)?**	
	Fluid/fuel volume	
	Number of GSE items	
	Multiple Techs required-(# of)	
	Multiple AFSCs required-(# of)	
	Internal or External Access	
5	How long does it take to **charge Aircraft main Batteries?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
6	How long does it take to **connect expired engine to engine stand?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
7	How long does it take to **test engine connection?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	

	Immediate results or Requires Additional Analysis	
8	How long does it take to **disconnect engine stand?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
9	How long does it take to **replace engine filter?**	
	Weight of component	
	Size of component	
	# of access panels needing removed	
	Number of GSE items	
	Multiple Techs required-(# of)	
10	How long does it take to **perform grounding procedures?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
11	How long does it take to **remove/replace standard/generic LRU?**	
	Weight of component	
	Size of component	
	# of access panels needing removed	
	Number of GSE items	
	Multiple Techs required-(# of)	
12	How long does it take to **place a new engine on engine stand?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
13	How long does it take to **position a maintenance engine stand?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
14	How long does it take to **perform an avionics function check?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
15	How long does it take to **perform a battery function check?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	

	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
16	How long does it take to **perform a generic electrical connections check?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
17	How long does it take to **perform engine function/status checks?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
18	How long does it take to **perform engine controls checks?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
19	How long does it take to **perform engine diagnostics?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
20	How long does it take to **perform sensor tests/diagnostics?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
21	How long to perform **aft safety assessment?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
22	How long to perform **forward safety assessment?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
23	How long to **move ground crew into position?**	

	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
24	How long for **ground crew to receive safety/self assessment?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
25	How long to **safe INS Recorder?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
26	How long to **Install ground lock pins & vent plugs?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
27	How long to **Install protective system (covers)?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
28	How long to **safe engines?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
29	How long to **Interrogate on-board system reporters?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
30	How long to **position Ground support equipment?**	
	Fluid/fuel volume	
	Number of GSE items	
	Multiple Techs required-(# of)	
	Multiple AFSCs required-(# of)	

	Internal or External Access	
31	How long does it take to **Shutdown APU?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
32	How long does it take to **Check Flight controls?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
33	How long does it take to **Perform a lubrication check?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
34	How long does it take to **R2 Engine Wire Harness?**	
	Weight of component	
	Size of component	
	# of access panels needing removed	
	Number of GSE items	
	Multiple Techs required-(# of)	
35	How long does it take to **Perform Hydraulic Fluid Condition Check?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
36	How long does it take to **Perform Hard landing inspection on tires/wheels?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
37	How long does it take to **R2 Fuel Pump?**	
	Weight of component	
	Size of component	
	# of access panels needing removed	
	Number of GSE items	
	Multiple Techs required-(# of)	
38	How long does it take to **R2 Batteries?**	
	Weight of component	
	Size of component	

	# of access panels needing removed	
	Number of GSE items	
	Multiple Techs required-(# of)	
39	How long does it take to **R2 Engine-Main?**	
	Weight (lbs) of component	
	Size (volume-cu in) of component	
	# of access panels needing removed	
	Number of GSE items	
	Multiple Techs required-(# of)	
40	How long does it take to **install/load ordnance on Aircraft?**	
	Fluid/fuel volume	
	Number of GSE items	
	Multiple Techs required-(# of)	
	Multiple AFSCs required-(# of)	
	Internal or External Access	
41	How long does it take to **unload post-flight unexpended ordnance on Aircraft?**	
	Fluid/fuel volume	
	Number of GSE items	
	Multiple Techs required-(# of)	
	Multiple AFSCs required-(# of)	
	Internal or External Access	
42	How long does it take to **return unexpended ordnance to storage?**	
	Fluid/fuel volume	
	Number of GSE items	
	Multiple Techs required-(# of)	
	Multiple AFSCs required-(# of)	
	Internal or External Access	
90	How long does it take to **prepare a/c for transport (towing)?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
91	How long does it take to **Position Hookup Tug?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
92	How long does it take to **Attach Tow Tug to a/c?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	

	Lifting Required–Ground-up–Waist-up	
93	How long does it take to **Check Tow Tug Connections?**	
	# Interfaces to interrogate	
	Specialized Equipment Required	
	Internal or External Access	
	Multiple Techs required-(# of)	
	Immediate results or Requires Additional Analysis	
94	How long does it take to **make Final Tow Preps?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
95	How long does it take to **TOW Aircraft to an open pad?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
96	How long does it take to **TOW Aircraft into a maintenance bay?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
99	How long does it take to **Configure for Handover to Ground Control Techs?**	
	Multiple Techs required-(# of)	
	Number of GSE items	
	Weight of component / Spt Equip	
	Internal or External Access	
	Lifting Required–Ground-up–Waist-up	
999	How Long does it take to **R2 individual Tile/TPS Blanket?**	
	Weight of component	
	Size of component	
	# of access panels needing removed	
	Number of GSE items	
	Multiple Techs required-(# of)	

Appendix D: MIL-PRF 38769D
Work Unit Code Preparation Manual
Appendix A, Tables IV, VIII, IX, and XIII

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APPENDIX A

TABLE IV. System codes (missile or spacecraft), ground launched.

11 AIRFRAME/BOOSTER STRUCTURE
12 ALL-UP-ROUND
13 WING AND FINFOLD
14 *
15 *
16 ORBITAL CRAFT STRUCTURE
17 SPACE FERRY AND/OR MANNED RE-ENTRY VEHICLE STRUCTURE
18 *
19 *
PROPULSION
21 *
22 *
23 TURBO JET
24 LIQUID ROCKET
25 SOLID ROCKET
26 ORBITAL MANEUVERING ENGINE
27 *
28 RETRO ROCKET (Excludes Primary Propulsion when used in Retro Fire Mode)
29 *
MISSILE OR SPACECRAFT ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS
31 AIR CONDITIONING (Including Atmospheric and Environmental Control)
32 PRESSURIZATION (When separate from Air Conditioning)
33 HYDRAULIC/PNEUMATIC POWER SUPPLY AND DISTRIBUTION
34 ELECTRICAL POWER SUPPLY AND DISTRIBUTION
35 ELECTRICAL DISTRIBUTION
36 *
37 SUBSISTENCE/WASTE
38 SPACE SUIT, LIFE SUPPORT AND PERSONAL MANEUVERING EQUIPMENT
39 MISCELLANEOUS
40 *
41 ARMAMENT AND EXPLOSIVE DEVICES
42 INITIATORS
43 DESTRUCT RANGE SAFE AND ARMING
45 STAGE SEPARATION
FLIGHT CONTROL

51 ORBITAL ATTITUDE MANEUVERING
52 FLIGHT CONTROL
53 *
54 *
55 AUTO PILOT
56 FLIGHT REFERENCE
57 COMBINED CONTROLS
58 DECELERATION AND SURFACE RECOVERY (Excludes Retro-Rocket)
59 *
GUIDANCE
61 COMMAND
62 INERTIAL
63 INTEGRATED GUIDANCE AND FLIGHT CONTROLS
64 NAVIGATOR/CELESTIAL
65 TARGET SEEKING
66 TRACKING
67 RENDEZVOUS RADAR
68 *
69 *
71 LIQUID ROCKET FUEL
72 LIQUID ROCKET OXIDIZER AND HYPERGOLIC
73 AIR BREATHING ENGINE FUEL
74 FUEL AND OXIDIZER PRESSURIZATION SYSTEMS
75 CHEMICAL
76 NUCLEAR MATERIALS
77 *
78 *
79 *
MISSILE RE-ENTRY SYSTEM
81 RE-ENTRY VEHICLE (Including Warhead, Arming and Fuzing)
82 RE-ENTRY SYSTEM (Including Penetration Aids)
83 *
84 *
85 *
86 *
87 *
88 *
89 *
COMMUNICATION AND DATA HANDLING
91 TELEMETRY
92 TRACKING AND RANGE INSTRUMENTATION
93 INTERCOM
94 COMMUNICATIONS
95 *
96 DATA RECORDING AND RETRIEVAL

97 *
98 RECONNAISSANCE
99 *
* These codes are unassigned. Their utilization shall require prior approval of the acquiring
activity.

TABLE VIII. Support general codes (except CE).

01000 GROUND HANDLING, SERVICING AND RELATED TASKS
Ground Handling (includes positioning, moving to a new position, or moving crashed or disabled equipment)
Loading and Unloading Engines/Cargo in Aircraft
Parking and Pre-Taxi (includes temporary parking, permanent parking, fireguard, SE operations, installation and removal of chocks, pins, locks, or covers)
Engine Runup
Drag Chute – Delivery, Installation, and Recovery
Mooring (tiedown, blade stoppage, installation of covers, etc.)
Flying – Flight Mechanics Performing Crew Duty
Launch Support Team Duty
Escort or Monitoring Visitors/Contractors
Monitoring Charging of Low Frequency/Low Cycle Fatigue (LF/LCF) Storage Batteries
Site Penetration/Back-Out
Dispatch Preparation (pre/post)
Water or Water/Alcohol Injection Fluid
Hydraulic Oil
Miscellaneous Servicing (includes anti-icing fluid, nitrogen, refrigerant, water, etc.)

RELATED TASKS
Armament (includes handling, routine cleaning, loading and unloading of guns and arms)
ATO/RATO Racks (servicing, loading, and unloading)
Bomb-practice, conventional, incendiary, and special stores; (includes servicing, loading and unloading of bombs, racks, dispensers, and associated equipment)
Rockets and Missiles Loading, Unloading and Servicing (includes dummy, checkout or test missiles, racks, launchers, etc.)
Tow Target/Tow Reel, etc
Radio and Radar Receiver/Transmitter Frequency Changes, and Installation or Removal of Crystals
Ballast (loading and unloading)
Identification Friend or Foe/Selectable Identification Feature (IFF/SIF)
Receiver/Transmitter Conversions or Codings

Passenger/Cargo Reconfiguration (includes installation and ramps, and auxiliary flooring)
Communications and Electronics Equipment Reconfiguration to Meet Mission Requirements (do not use for Time Compliance Technical Order (TCTO) accomplishment).
Tape Installation and Removal
Tape Development, Reproduction and Analysis
Electronic Countermeasures (ECM), Chaff or Equipment Loading and Unloading
Photographic – Equipment or Film Changes (loadings, or unloading, and film development
and analysis)
Electronic Spares (replacement)
SE Positioning, Pickup and Delivery
780 Equipment Pickup/Delivery (includes pickup/delivery of canopy covers, drag chutes, batteries, etc., to and from maintenance shops)
Survival Equipment (loading and unloading)
Pod, Pylon and External Tank Handling (includes installation and removal)
Refueling Boom (includes installation and removal)

02000 EQUIPMENT CLEANING
Washing, Decontamination, Snow, Frost and Ice Removal, Vacuuming, Wiping, Polishing,
Cleaning and Treating of Equipment to Prevent Corrosion (do not use this code for treating corroded parts or accessories)

05000 PRESERVATION, DEPRESERVATION, AND STORAGE OF EQUIPMENT

06000 WEAPON AND GROUND SAFETY
Arming and Disarming of Guns, Rockets, Explosive Squibs, Seats, Canopies, External Tanks/Pods/Pylon Ejectors, Armament Bay Doors, Missile Launchers, Wing and Fuselage Center Line Racks, Bomb Bay Release Mechanisms/Controls, etc. Also includes Connecting and Disconnecting Aircraft Batteries

07000 PREPARATION AND MAINTENANCE OF RECORDS
This code Will be Used by Maintenance Personnel to Record Only the Direct Labor Expended in Preparation/Maintenance of Status and Historical Forms (this excludes initiation and completion of production documentation forms)

09000 SHOP SUPPORT GENERAL CODES
Fabricating (includes bending, cutting, forming, casting, holding, machining, soldering, assembly, local manufacture, etc., not done as part of a fix on a specific job)
Stenciling/Painting (includes stenciling, lettering, installing decals, instrument range marking, etc., and painting for cosmetic purposes only). Do Not Use This Code For Treating Corrosion or Painting of Parts/Assemblies/Equipment For Corrosion Prevention/Control Engine/or Power Pack Buildup or Teardown Engine Operation – Test

Stand (includes installation of engines in test stand) Wheel and Tire Buildup or Teardown Cleaning/Servicing (includes recharging, sandblast, degreasing, preparation for, and/or removal from storage or shipment, etc.) Reclamation (includes demilitarization, disassembly, preparation for resale, and disposal of aerospace and nonaeronautical equipment) Processing of Small Arms and Ammunition
Inspection/Repack of Parachutes (all types)
Inspection/Repack of Flotation Equipment
Inspection of Personal Equipment (includes helmets, specialized flight suits, etc.)
Fabric Testing
Plating (includes cleaning and preparation for plating)
Testing and Servicing Fire Extinguishers

TABLE IX. Support general codes CE.

01000 GROUND HANDLING, SERVICING AND RELATED TASKS
Ground Handling.
Equipment Moving or Repositioning
Installation/Relocation of Equipment
Removal of Equipment
Mission Equipment Operation or Support When Not Associated With Scheduled or Unscheduled Maintenance
Servicing and Related tasks.
Scheduled Power Changeover
Troubleshooting End Items or Facilities (use only for end items or facilities that do not have a WUC assigned)
Unscheduled Power Changeover
Power Production Service and Checkout
Environmental Control
Rehabilitation of Antenna Systems
Unscheduled Antenna System Service
Clearing of Antenna/Transmission Right-of-Way
Installation of New Antenna System
Receiver or Transmitter Frequency Changes
Tape Development, Reproduction and Analysis
Telephone Number Change
Rehabilitation of Equipment

02000 EQUIPMENT AND FACILITY CLEANING
Washing or Degreasing
Cleaning and Treating Equipment to Prevent Corrosion
Ground Snow, Frost and Ice removal
Cleaning Antenna Systems, Mobile Facilities, and Fixed Facilities

Decontamination

05000 PRESERVATION, DEPRESERVATION, AND STORAGE OF CE EQUIPMENT

06000 GROUND SAFETY

07000 PREPARATION AND MAINTENANCE OF RECORDS
This Code Will be Used to Record Only the Direct Labor Expended in Preparation/Maintenance of Status and Historical Forms (this excludes initiation and completion of production documentation forms).

09000 SHOP SUPPORT GENERAL CODE
Fabricate (Includes fabrication or local manufacture of miscellaneous items). Stenciling/Painting (includes stenciling, lettering, installing decals, instrument range marking, etc., and painting for cosmetic purposes only). Do Not Use This Code For Treating Corrosion or Painting of Parts/Assemblies/Equipment For Corrosion Prevention/Control. Testing and Servicing Fire Extinguishers Reclamation

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APPENDIX A

TABLE XIII. Ground launched missile support general codes.

"LOOK" PHASE OF SCHEDULED AND SPECIAL INSPECTIONS
SCHEDULED INSPECTIONS
Code Description
03100 Receiving Inspection (includes assembly)
03110 Inspection Crews
0311K Armament
0311L Shelter Maintenance
0311M Ramjet
0311N Missile Maintenance
0311P Missile Interface Unit (MIU)
0311Q Mobile Ground Power
0311R Fueling
0311S Disassembly
0311T SMATE
0311U IMSOC
03200 Installation (do not use for missile to launcher installation)
03300 Pre-Launch
03400 Daily
03500 Periodic (phase if authorized)
03107 7 Day
03114 14 Day

03510 15 Day
03121 21 Day
03128 28 Day
03520 30 day
03142 42 Day
03156 56 Day
03530 60 Day
03184 84 Day
03540 90 Day
03268 168 Day
03550 180 Day
03336 336 Day
03560 360 Day
03570 Control Equipment
03580 Armament Test Equipment
03600 Post-Launch/Static Firing
03700 Storage
03701 Storage Inspection
03800 Re-entry Vehicle Recycle
03802 Re-entry Vehicle Recycle for Higher Headquarter Evaluation
03803 Re-entry Vehicle Recycle for Time Compliance Technical Order (TCTO)
03804 Re-entry Vehicle for Limited Life Component/Technical Critical Item (LLC/TCI) Replacement
03806 Disassembly for Operational Test/Follow-on Operational test (OT/FOT)
03807 Assembly for OT/FOT

SPECIAL INSPECTIONS
04110 Pressure Checks, Warheads
04111 Nuclear Certification
04112 Nuclear Decertification
04120 Missile/Shelter Reset
04130 Pressure Check, Air Bottle
04141 Corrosion Control Inspections Accomplished Separately From Scheduled Inspections
04500 Accomplishment of Checklists
04572 Missile/Launch Verification (Simulation)
04573 Missile/Launch Verification (No Simulation)
04574 Missile Verification
04575 Launch Verification (Simulation)
04576 Launch Verification (No Simulation)
04577 Dynamic Response Test
04578 Combined Systems Test
04583 Thrust Maintenance Operation
04584 Silo Door Operation
04650 Initial Build-up-Recovery Vehicle (RV)

04610 Nondestructive Testing (all types)
04630 Research and Development of New or Revised Nondestructive Inspection Techniques
04999 Special Inspections Not Otherwise Coded
04111 Operational or System Check
04112 Special Modification Inspection
04113 Air or Ground Right-of-Way Inspection (includes intersite cable system, fences, insulators, posts, cable markers, etc.)
04141 Corrosion Control Inspections Accomplished Separately From Scheduled Inspections
04610 Nondestructive testing (all types)
04620 Analysis of Oil Samples
04630 Research and Development of New or Revised Nondestructive Inspection Techniques

Appendix E: Notional MILEPOST Work Unit Code Structure

The following WUC Structure is organized alphabetically by the processes within the four phases of the simulation (Integration, Launch, Maintenance, Post-Flight). Each Arena process number is listed with a description of that process. Under each listing is the notional WUC associated with that process. Some processes have a System code and support code(s) associated, while some are just support codes.

<u>INTEGRATION PHASE:</u>

Arena Process # 51		**1st 2nd stage integration check off pad**
	03100	SCHEDULED / Receiving Inspection (includes assembly)
	04500	SPECIAL / Accomplishment of Checklists
Arena Process # 25		**1st 2nd stage integration check on pad**
	03100	SCHEDULED / Receiving Inspection (includes assembly)
	04500	SPECIAL / Accomplishment of Checklists
Arena Process # 56		**1st and 2nd stage integration check off pad 1**
	03100	SCHEDULED / Receiving Inspection (includes assembly)
	04500	SPECIAL / Accomplishment of Checklists
Arena Process # 95		**1st stage fuel chill and fill**
71xxx	71KA0	LIQUID ROCKET FUEL / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY
Arena Process # 92		**1st stage fuel chill and fill 1**
71xxx	71KA0	LIQUID ROCKET FUEL / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY
Arena Process # 89		**1st stage fuel chill and fill 2**
71xxx	71KA0	LIQUID ROCKET FUEL / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY
Arena Process # 83		**1st stage LOX chill and fill**
72xxx	72KA0	LIQUID ROCKET OXIDIZER AND HYPERGOLIC / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY
Arena Process # 85		**1st stage LOX chill and fill 1**
72xxx	72KA0	LIQUID ROCKET OXIDIZER AND HYPERGOLIC / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 87 **1st stage LOX chill and fill 2**

72xxx	72KA0	LIQUID ROCKET OXIDIZER AND HYPERGOLIC / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 94 **2nd stage fuel chill and fill**

71xxx	71KA0	LIQUID ROCKET FUEL / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 93 **2nd stage fuel chill and fill 1**

71xxx	71KA0	LIQUID ROCKET FUEL / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 90 **2nd stage fuel chill and fill 2**

71xxx	71KA0	LIQUID ROCKET FUEL / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 84 **2nd stage LOX chill and fill**

72xxx	72KA0	LIQUID ROCKET OXIDIZER AND HYPERGOLIC / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 86 **2nd stage LOX chill and fill 1**

72xxx	72KA0	LIQUID ROCKET OXIDIZER AND HYPERGOLIC / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 88 **2nd stage LOX chill and fill 2**

72xxx	72KA0	LIQUID ROCKET OXIDIZER AND HYPERGOLIC / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 9 **Align payload with second stage**

01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 52 **Attach handling equipment to 2nd stage off pad**

01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 37 **Attach handling equipment to 2nd stage payload off pad**

01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 47 **Attach handling fixture to 2^{nd} stage off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 21 **Attach handling fixture to 2^{nd} stage on pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 33 **Attach handling fixture to 2^{nd} stage payload off pad**

01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 15 **Attach handling fixture to 2^{nd} stage payload on pad**

01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 31 **Attach handling fixture to HLV off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 45 **Attach handling fixture to HLV off pad 1**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 13 **Attach handling fixture to HLV on pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 19 **Attach handling fixture to HLV on pad no preint**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 8 **Attach handling fixture to payload**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 41 **Attach payload handling equipment off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 26 **Attach payload handling equipment on pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 66 **Attach payload handling equipment on pad 1**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 64 **Attach the erecting mechanism**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 61 **Attach transporter**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Loading and Unloading Cargo"

Arena Process # 73 **Electrical and comm connections**
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 57 **Entire vehicle integration check off pad**
03200 SCHEDULED / Installation
04500 SPECIAL / Accomplishment of Checklists

Arena Process # 30 **Entire vehicle integration check on pad**
03200 SCHEDULED / Installation
04500 SPECIAL / Accomplishment of Checklists

Arena Process # 70 **Entire vehicle integration check on pad 1**
03200 SCHEDULED / Installation
04500 SPECIAL / Accomplishment of Checklists

Arena Process # 48 **Erect and position 2nd stage off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 22 **Erect and position 2nd stage on pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 34 **Erect and position 2nd stage payload off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 32 **Erect and position HLV on MLP off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 46 **Erect and position HLV on MLP off pad 1**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 14 **Erect and position HLV on pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 20 **Erect and position HLV on pad no preint**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 65 **Erect vehicle and secure to launch platform**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 82 **Final TPS or other inspection**

82xxx	82ZA0	RE-ENTRY SYSTEM / Miscellaneous
	03300	SCHEDULED / Pre-Launch
	04500	SPECIAL / Accomplishment of Checklists

Arena Process # 76 **Fuel RP first stage**

71xxx	71KB0	LIQUID ROCKET FUEL / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 77 **Fuel RP first stage 1**

71xxx	71KB0	LIQUID ROCKET FUEL / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 79 **Fuel RP first stage 2**

71xxx	71KB0	LIQUID ROCKET FUEL / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 78 **Fuel RP second stage**

71xxx	71KB0	LIQUID ROCKET FUEL / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 80 **Fuel RP second stage 1**

71xxx	71KB0	LIQUID ROCKET FUEL / PROPELLANT LOADING
	0311R	SCHEDULED / Fueling Inspection
	06000	WEAPON AND GROUND SAFETY

Arena Process # 81 **Install arm ordnance**

16xxx	16BA0	ORBITAL CRAFT STRUCTURE / LAUNCHER
	06000	WEAPON AND GROUND SAFETY / Arming
	0311K	SCHEDULED / Armament

Arena Process # 59 **Install ordnance off pad**

16xxx	16BA0	ORBITAL CRAFT STRUCTURE / LAUNCHER
	06000	WEAPON AND GROUND SAFETY / Arming
	0311K	SCHEDULED / Armament

Arena Process # 16 **Lift and align 2nd stage payload on pad**

	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 27 **Lift and align payload on pad**

	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 67 **Lift and align payload on pad 1**

	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 42 **Lift or position and align payload off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 58 **Load hypergolic fuel off pad**
72xxx 72KA0 LIQUID ROCKET OXIDIZER AND HYPERGOLIC / PROPELLANT LOADING
0311R SCHEDULED / Fueling Inspection
06000 WEAPON AND GROUND SAFETY

Arena Process # 75 **Load hypergolic fuel on pad**
72xxx 72KA0 LIQUID ROCKET OXIDIZER AND HYPERGOLIC / PROPELLANT LOADING
0311R SCHEDULED / Fueling Inspection
06000 WEAPON AND GROUND SAFETY

Arena Process # 40 **Make electric connections off pad 1**
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 11 **Make electrical connections**
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 36 **Make electrical connections off pad**
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 50 **Make electrical connections off pad 2**
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 55 **Make electrical connections off pad 3**
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 18 **Make electrical connections on pad**
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 24 **Make electrical connections on pad no preint**
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 29 **Make electrical connections payload on pad**
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 69 **Make electrical connections payload on pad 1**
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 10 **Make mechanical connections**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 35 **Make mechanical connections off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 39 **Make mechanical connections off pad 1**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 49 **Make mechanical connections off pad 2**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 54 **Make mechanical connections off pad 3**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 17 **Make mechanical connections on pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 23 **Make mechanical connections on pad no preint**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 28 **Make mechanical connections payload on pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 68 **Make mechanical connections payload on pad 1**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 44 **Make payload electrical connections off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 43 **Make payload mechanical connections off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 7 **Move vehicle to integration facility**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 6 **Move vehicle to launch pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 38 **Position align 2nd stage payload off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 53 **Position and align 2nd stage off pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 63 **Position MLP on launch pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 71 **Propellant connections**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Refueling Boom / Launch Support Team Duty"

Arena Process # 12 **second stage and payload integration check**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 60 **Transport preparations**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 62 **Transport vehicle to pad**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 72 **Umbilical leak check**
0311R SCHEDULED / Fueling Inspection
03300 SCHEDULED / Pre-Launch
06000 WEAPON AND GROUND SAFETY

Arena Process # 74 **Verify electrical and comm connectivity**
03570 SCHEDULED / Control Equipment Inspection
03300 SCHEDULED / Pre-Launch

<u>LAUNCH PHASE:</u>

Arena Process # 96 **Launch**
04576 SPECIAL / Launch (No Simulation)

Arena Process # 91 **Terminal countdown**
04577 SPECIAL / Launch (No Simulation)

<u>MAINTENANCE PHASE:</u>

Arena Process # 101 **Avionics Testing**
52xxx 52MA0 "FLIGHT CONTROL / Guidance, Tracking Network and Instrumentation"
03570 SCHEDULED / Control Equipment Inspection

Arena Process # 105 Battery testing

34xxx 34JA0 ELECTRICAL POWER SUPPLY AND DISTRIBUTION / Electrical Generation and Distribution

01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Monitoring Charging of Storage Batteries"

06000 WEAPON AND GROUND SAFETY / Connecting and Disconnecting Batteries

Arena Process # 108 Buffer Plug R2

58xxx 58QA0 COMBINED CONTROLS / Communications

01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 104 Charge Batteries

34xxx 34JA0 ELECTRICAL POWER SUPPLY AND DISTRIBUTION / Electrical Generation and Distribution

01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Monitoring Charging of Storage Batteries"

06000 WEAPON AND GROUND SAFETY / Connecting and Disconnecting Batteries

Arena Process # 120 Connect motor stand

24xxx 24FA0 LIQUID ROCKET / Handling Equipment

09000 SHOP SUPPORT GENERAL CODES / Engine Operation Test Stand

Arena Process # 1 Connect to Stage1

01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

Arena Process # 127 Connection Test

24xxx 24SA0 LIQUID ROCKET / Systems Test Equipment

04111 SPECIAL / Operational or System Check Inspection

04500 SPECIAL / Accomplishment of Checklists

Arena Process # 136 Curing

82xxx 82ZA0 RE-ENTRY SYSTEM / Miscellaneous

09000 SHOP SUPPORT GENERAL CODES / Fabricating / Assembly / Local Manufacture

Arena Process # 121 Disco Elect from Stage1

24xxx 24JA0 LIQUID ROCKET / Electrical Generation and Distribution

01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"

09000 SHOP SUPPORT GENERAL CODES / Engine Buildup or Teardown

Arena Process # 122 Disco Mech from Stage1

24xxx 24ZA0 LIQUID ROCKET / Miscellaneous

09000 SHOP SUPPORT GENERAL CODES / Engine Buildup or Teardown

Arena Process # 130 Disco stand

24xxx 24FA0 LIQUID ROCKET / Handling Equipment

09000 SHOP SUPPORT GENERAL CODES / Engine Operation Test Stand

Arena Process # 128 Disco stand and remove

24xxx 24FA0 LIQUID ROCKET / Handling Equipment

09000 SHOP SUPPORT GENERAL CODES / Engine Operation Test Stand

Arena Process # 5 **Disconnect from Stage1**
09000 SHOP SUPPORT GENERAL CODES /Reclamation
0311S SCHEDULED / Disassembly Inspection

Arena Process # 129 **Drag Chute**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Drag Chute - Delivery, Installation, and Recovery"
09000 SHOP SUPPORT GENERAL CODES / Inspection - Repack of Parachutes

Arena Process # 126 **Elect Conn motor**
24xxx 24JA0 LIQUID ROCKET / Electrical Generation and Distribution
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"
09000 SHOP SUPPORT GENERAL CODES / Engine Buildup or Teardown

Arena Process # 99 **Electrical Connections 2**
01000 "CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"
04999 SPECIAL / Special Inspection Not Otherwise Coded

Arena Process # 142 **Engine checkout**
24xxx 24SA0 LIQUID ROCKET / Systems Test Equipment
04111 SPECIAL / Operational or System Check Inspection
04500 SPECIAL / Accomplishment of Checklists

Arena Process # 114 **Engine Controls**
52xxx 52MA0 "FLIGHT CONTROL / Guidance, Tracking Network and Instrumentation"
03570 SCHEDULED / Control Equipment Inspection

Arena Process # 140 **Engine Diagnostics**
24xxx 24SA0 LIQUID ROCKET / Systems Test Equipment
04111 SPECIAL / Operational or System Check Inspection
04500 SPECIAL / Accomplishment of Checklists

Arena Process # 111 **Filters 1**
24xxx 24KA0 LIQUID ROCKET / Propellant
09000 SHOP SUPPORT GENERAL CODES / Engine Operation Test Stand

Arena Process # 112 **Filters 2**
24xxx 24KA0 LIQUID ROCKET / Propellant
09000 SHOP SUPPORT GENERAL CODES / Engine Operation Test Stand

Arena Process # 102 **Flight Controls**
52xxx 52MA0 "FLIGHT CONTROL / Guidance, Tracking Network and Instrumentation"
03570 SCHEDULED / Control Equipment Inspection

Arena Process # 134 **Gap Filler R2**
82xxx 82ZA0 RE-ENTRY SYSTEM / Miscellaneous
09000 SHOP SUPPORT GENERAL CODES / Fabricating / Assembly / Local Manufacture

Arena Process # 4		**Grounding procedures**
	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Mooring"
Arena Process # 138		**HLV systems check**
82xxx	82ZA0	RE-ENTRY SYSTEM / Miscellaneous
	04999	SPECIAL / Special Inspection Not Otherwise Coded
Arena Process # 109		**hydraulic condition**
33xxx	33CA0	HYDRAULIC / Servicing Equipment
	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Hydraulic Oil"
Arena Process # 97		**Interrogate Maintenance Reporter**
	01000	"CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"
	04111	SPECIAL / Operational or System Check Inspection
Arena Process # 117		**Landing Gear and tires**
16xxx	16XA0	ORBITAL CRAFT STRUCTURE / Real Property Installed Equipment
	09000	SHOP SUPPORT GENERAL CODES / Wheel and Tire Buildup or Teardown
	03600	SPECIAL / Post-Launch Inspection
Arena Process # 116		**Linkage**
	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"
Arena Process # 113		**LRU R2**
74xxx	74KA0	FUEL SYSTEMS / PROPELLANT LOADING AND STORAGE
Arena Process # 110		**Lubrication check**
	04999	SPECIAL / Special Inspection Not Otherwise Coded
Arena Process # 125		**mech connect motor to Stage1**
24xxx	24ZA0	LIQUID ROCKET / Miscellaneous
	09000	SHOP SUPPORT GENERAL CODES / Engine Buildup or Teardown
Arena Process # 115		**Nozzles**
24xxx	24ZA0	LIQUID ROCKET / Miscellaneous
	09000	SHOP SUPPORT GENERAL CODES / Engine Buildup or Teardown
Arena Process # 124		**place new motor and stand**
24xxx	24FA0	LIQUID ROCKET / Handling Equipment
	09000	SHOP SUPPORT GENERAL CODES / Engine Operation Test Stand
Arena Process # 98		**Position Maintenance stands**
	09000	SHOP SUPPORT GENERAL CODES
Arena Process # 3		**Position Stage1 in Maintenance Bay**
	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"
Arena Process # 118		**Preplanned maintenance**
	03800	SCHEDULED / Re-entry Vehicle Recycle

Arena Process # 141		**Pumps and fuel system**
74xxx	74KB0	FUEL SYSTEMS / PROPELLANT LOADING AND STORAGE
Arena Process # 137		**Recheck TPS**
82xxx	82ZA0	RE-ENTRY SYSTEM / Miscellaneous
	03600	SCHEDULED / Post-Launch
	04500	SPECIAL / Accomplishment of Checklists
Arena Process # 123		**Remove Motor**
24xxx	24ZA0	LIQUID ROCKET / Miscellaneous
	09000	SHOP SUPPORT GENERAL CODES / Engine Buildup or Teardown
Arena Process # 103		**Replace Batteries**
34xxx	34JA0	ELECTRICAL POWER SUPPLY AND DISTRIBUTION / Electrical Generation and Distribution
	06000	WEAPON AND GROUND SAFETY / Connecting and Disconnecting Batteries
Arena Process # 135		**Sealant Application**
82xxx	82ZA0	RE-ENTRY SYSTEM / Miscellaneous
Arena Process # 143		**SensorEquipment**
	01000	"CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment"
	04111	SPECIAL / Operational or System Check Inspection
Arena Process # 107		**Stage2 Area Hardware**
	09000	SHOP SUPPORT GENERAL CODES / Fabricating / Assembly / Local Manufacture
Arena Process # 106		**Stage2 Mech Conn**
	09000	SHOP SUPPORT GENERAL CODES / Fabricating / Assembly / Local Manufacture
Arena Process # 119		**TCTO actions**
	03803	SCHEDULED / Re-entry Vehicle Recycle for Time Compliance Technical Order
Arena Process # 133		**Thermal Barrier Repair**
82xxx	82ZA0	RE-ENTRY SYSTEM / Miscellaneous
Arena Process # 132		**Tile and Blanket** R2
82xxx	82ZA0	RE-ENTRY SYSTEM / Miscellaneous
Arena Process # 2		**Transport to Maintenance Bay**
	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"
Arena Process # 100		**Upper Stage Electrical Connecting Point Testing**
	01000	CE GROUND HANDLING, SERVICING AND RELATED TASKS / Installation of Equipment
Arena Process # 131		**Visual Check TPS**
82xxx	82ZA0	RE-ENTRY SYSTEM / Miscellaneous
	04999	SPECIAL / Special Inspection Not Otherwise Coded

Arena Process # 139 **Waterproof TPS**
82xxx 82ZA0 RE-ENTRY SYSTEM / Miscellaneous

POST-FLIGHT PHASE:

Arena Process # 164 **Aft Safety Assessments**
03600 SCHEDULED / Post-Launch
04500 SPECIAL / Accomplishment of Checklists

Arena Process # 172 **APU Shutdown**
34xxx 34JB0 ELECTRICAL POWER SUPPLY AND DISTRIBUTION / Electrical Generation and Distribution

Arena Process # 169 **Attach Tow Tug to RMLV**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 170 **Check Tow Tug Connections**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"
04999 SPECIAL / Special Inspection Not Otherwise Coded

Arena Process # 149 **Configure for Handover to Spaceport Ground Control**

01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Miscellaneous servicing"

Arena Process # 148 **Connect Coolant GSE Umbilicals**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Miscellaneous servicing"

Arena Process # 146 **Connect Purge and Inerting GSE Umbilicals and Monitor**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Miscellaneous servicing"

Arena Process # 155 **Final Tow Preps**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 145 **Forward Safety Assessments**
03600 SCHEDULED / Post-Launch
04500 SPECIAL / Accomplishment of Checklists

Arena Process # 176 **Ground Crew and GSE moved into position**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 173 **Ground Crew Receives Safety Self Assessment**
03600 SCHEDULED / Post-Launch

Arena Process # 160 **Hydrozine Circulation Pump Safing**
72xxx 72CA0 LIQUID ROCKET OXIDIZER AND HYPERGOLIC / Servicing Equipment
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Miscellaneous servicing"
04500 SPECIAL / Accomplishment of Checklists

Arena Process # 151 **Initiate Ground Cooling**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Miscellaneous servicing"

Arena Process # 147 **Initiate Purge and Monitor**
06000 WEAPON AND GROUND SAFETY

Arena Process # 165 **INS Recorder Safing**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Miscellaneous servicing"

Arena Process # 150 **Install Ground Lock Pins and Vent Plugs**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Parking and Pre-taxi operations"

Arena Process # 153 **Install MPS and RMLV Protective Covers**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Mooring"

Arena Process # 168 **Load and Remove External Stores**
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Special Stores"
06000 WEAPON AND GROUND SAFETY

Arena Process # 175 **LOX Safing**
72xxx 72KA0 LIQUID ROCKET OXIDIZER AND HYPERGOLIC / PROPELLANT LOADING
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Miscellaneous servicing"
0311R SCHEDULED / Fueling Inspection

Arena Process # 159 **Main Propulsion System Configuration**
24xxx 24SB0 LIQUID ROCKET / Systems Test Equipment
04111 SPECIAL / Operational or System Check Inspection
04500 SPECIAL / Accomplishment of Checklists

Arena Process # 152 **Monitor On board Systems**
04111 SPECIAL / Operational or System Check Inspection
01000 "GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Arena Process # 162 **MX Delay for Safety Downgrade**
02000 EQUIPMENT CLEANING / Decontamination
06000 WEAPON AND GROUND SAFETY

Arena Process # 163 **MX Delay Safety for Haz Gas**
02000 EQUIPMENT CLEANING / Decontamination
06000 WEAPON AND GROUND SAFETY

Arena Process # 157		**OMS RCS System Safing**
	06000	WEAPON AND GROUND SAFETY
Arena Process # 166		**Position External Store GSE**
	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Miscellaneous servicing"
Arena Process # 154		**Position Hookup Tug**
	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"
Arena Process # 144		**Reaction Jet Drive and Drag Chute Pyro Safing**
	06000	WEAPON AND GROUND SAFETY
Arena Process # 171		**RMLV Taxi to Recovery Apron**
	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"
Arena Process # 167		**Separate External Stores**
	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Special Stores"
	06000	WEAPON AND GROUND SAFETY
Arena Process # 161		**Stow Air Data Probes**
	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Miscellaneous servicing"
Arena Process # 174		**Superficial TPS and debris Inspection**
82xxx	82ZA0	RE-ENTRY SYSTEM / Miscellaneous
	03300	SCHEDULED / Pre-Launch
	04500	SPECIAL / Accomplishment of Checklists
Arena Process # 158		**Tank Vent RMLVME**
71xxx	71KB0	LIQUID ROCKET FUEL / Propellant Storage
	06000	WEAPON AND GROUND SAFETY
Arena Process # 156		**TOW RMLV**
	01000	"GROUND HANDLING, SERVICING AND RELATED TASKS / Positioning / Moving to a new position / Launch Support Team Duty"

Appendix F: WUC Structure Comments/Recommendations, Validated by REMIS System Analyst

From: 754 ELSG/LRX
Sent: Friday, February 08, 2008 11:48 AM
To: Servidio Joseph A Capt AFIT/ENS
Subject: RE: Review of Notional WUC Structure

Capt Servidio,

I have a couple observations regarding your proposed WUC list:

1) You use WUC 09000 (Shop Support General Codes) quite often for 'assembly'. I'm guessing they are rigs attached to aid in ground handling. WUC 09000 would be used if you are 'assembling' fabricated parts into an assembly prior to it being installed on the RV, but not to install a fabricated item to the RV. Any component installation is done using the component WUC (install/remove/repair). This sounds more like it's part of ground handling, like attaching a towbar to the aircraft to relocate it or putting an aircraft engine on a trailer to move it to the hush house – where you'd use 01000.

(JAS) All 09000 WUCs have been reviewed and verified that the intent of each of the associated processes is essentially the same as loading payload. Therefore, the applicable 09000 codes have been changed to 01000, Ground Handling, as recommended.

2) A few system-level WUCs are labeled 'Liquid Rocket Fuel/propellant loading' (list 72KA0, 71KA0, and 71KB0). A system-level WUC represents a tangible component that can be installed, removed, or repaired (installing a fuel tank vs. filling it). Topping of any fluids (fuel, hydraulic, oil, coolant, etc) is documented against 01000. In the same processes, you list 0311R as 'fueling inspection' which is different than the servicing action, itself. This would be used to inspect for leaks after fueling (notice there is no WUC for defueling) and not for the actual servicing.

Along the same lines - #158 goes to Propellant Storage – the propellant is not a component of the RV – it's fuel that is serviced. You can have a WUC to address the de-fueling of the tanks, but the subsequent storage of the propellant becomes a supply or POL issue at that point. Again, 71KB0 would be used to identify any maintenance (install/remove/repair) or the Liquid Rocket Fuel SYSTEM, and not the fueling/defueling process, itself.

(JAS) The intent of identifying 71xxx and 72xxx system level WUCs is to provide a generic point of reference corresponding to a system-level WUC. It is understood that the no specific maintenance action is occurring directly with that System-level part.

(JAS) All fluid filling processes will have the 01000 WUC added against them.

(JAS) It is implied that a fueling inspection will be conducted upon completion of fueling actions, thus the 0311R code is identified.

(JAS) Additionally, WUC 06000, Weapon and Ground Safety, will be added to all processes involving fluids/hazards. Again, it is implied that safety reps will be involved by observing the process.

3) What is the 03200 scheduled / installation inspection about? I'm guessing this is the last major look-over of any component installation on the RV, off- then on- the pad, prior to launch? If so, I think 03200 is appropriate – like having the referee review a play after a line judge called a foul.

4) In Arena Process #82, you list 82ZA0 as Re-Entry System / Miscellaneous – can you elaborate? I suspect you are using this to catch any other installation/repair that doesn't necessarily have a WUC established. There are specific WUCs built to capture those, based on the parent sub-system they belong to. I can provide samples if you need them.

(JAS) Process #82 refers to a Thermal Protection System (TPS), heat shield tiles, which are part of the Re-Entry System. Thus the 82xxx code is identified as the System-level code associated with the TPS inspection.

5) And as you stated, a more thorough list would be required if this were to be loaded into REMIS. All major systems, sub-systems, and their components would need WUCs. Within each system/sub-system, you would include WUCs, listed as 'Not Otherwise Coded' or NOC, to capture actions done on equipment that did not already have a specific WUC loaded for it. Your support general list would also need to be expanded (NDI inspections, fuel contamination, cleaning, battery inspections, etc).

(JAS) For now, these codes and processes are compatible with REMIS. Of course, future research and design methods would identify significantly more detailed data regarding specific RMLV parts and/or processes, which would result in a much more lengthy and elaborate WUC structure.

I know this is only a sampling of your table, but if you still have questions about the construction of WUC tables, you could come out to our building and I could show you samples of how they are built.

Contractor, LOGTEC (a wholly owned subsidiary of SI International)
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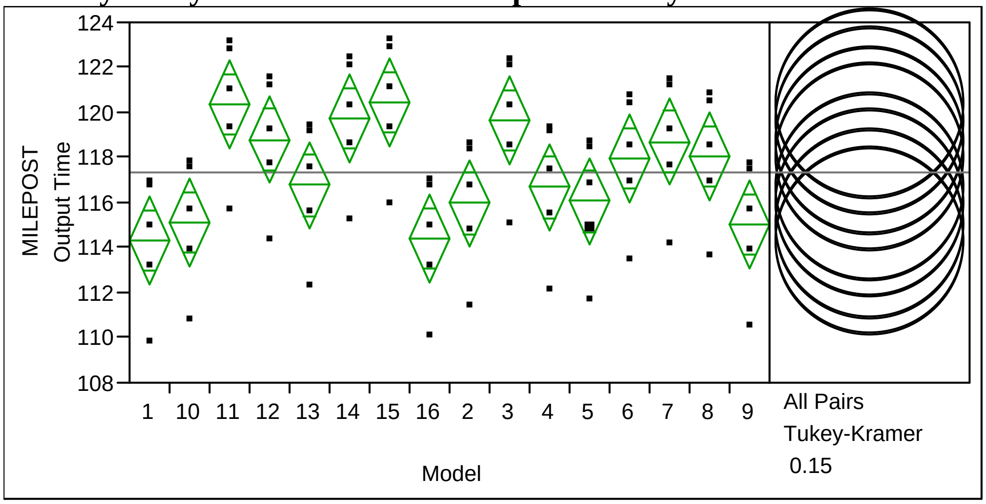
Note: All comments prefaced by (JAS) were provided by the author of this research in response to the WUC structure review.

Appendix G. Experimental Design Results

<u>Preintegration Design Decision:</u>

Oneway Analysis of MILEPOST Output Time By Model



Oneway Anova
Summary of Fit

Rsquare	0.37449
Adj Rsquare	0.227886
Root Mean Square Error	2.956885
Mean of Response	117.3708
Observations (or Sum Wgts)	80

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	15	335.00800	22.3339	2.5544	0.0048
Error	64	559.56283	8.7432		
C. Total	79	894.57083			

Means for Oneway Anova

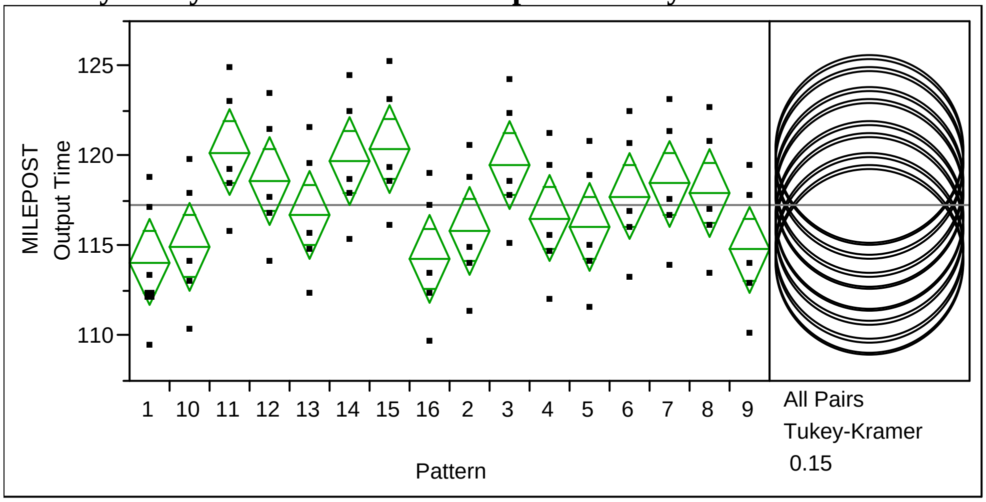
Level	Number	Mean	Std Error	Lower 85%	Upper 85%
1	5	114.299	1.3224	112.37	116.23
10	5	115.111	1.3224	113.18	117.04
11	5	120.355	1.3224	118.43	122.28
12	5	118.777	1.3224	116.85	120.70
13	5	116.777	1.3224	114.85	118.70
14	5	119.718	1.3224	117.79	121.64
15	5	120.443	1.3224	118.52	122.37
16	5	114.387	1.3224	112.46	116.31
2	5	115.964	1.3224	114.04	117.89
3	5	119.630	1.3224	117.70	121.56
4	5	116.689	1.3224	114.76	118.62
5	5	116.052	1.3224	114.12	117.98
6	5	117.965	1.3224	116.04	119.89
7	5	118.690	1.3224	116.76	120.62
8	5	118.053	1.3224	116.13	119.98
9	5	115.023	1.3224	113.10	116.95

Tukey Results: Levels not connected by same letter are significantly different:

Level			Mean
15	A		120.44333
11	A		120.35547
14	A	B	119.71823
3	A	B	119.63037
12	A	B	118.77746
7	A	B	118.68961
8	A	B	118.05317
6	A	B	117.96531
13	A	B	116.77676
4	A	B	116.68890
5	A	B	116.05166
2	A	B	115.96380
10	A	B	115.11089
9	A	B	115.02304
16		B	114.38660
1		B	114.29874

No Preintegration Design Decision:

Oneway Analysis of MILEPOST Output Time By Pattern



Oneway Anova

Summary of Fit

Rsquare	0.27893
Adj Rsquare	0.10993
Root Mean Square Error	3.712068
Mean of Response	117.2476
Observations (or Sum Wgts)	80

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Pattern	15	341.1383	22.7426	1.6505	0.0851
Error	64	881.8849	13.7795		
C. Total	79	1223.0233			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 85%	Upper 85%
1	5	114.098	1.6601	111.68	116.52
10	5	114.971	1.6601	112.55	117.39
11	5	120.221	1.6601	117.80	122.64
12	5	118.638	1.6601	116.22	121.06
13	5	116.731	1.6601	114.31	119.15
14	5	119.701	1.6601	117.28	122.12
15	5	120.398	1.6601	117.98	122.82
16	5	114.275	1.6601	111.86	116.69
2	5	115.857	1.6601	113.44	118.28
3	5	119.524	1.6601	117.10	121.94

Level	Number	Mean	Std Error	Lower 85%	Upper 85%
4	5	116.554	1.6601	114.14	118.97
5	5	116.034	1.6601	113.62	118.45
6	5	117.764	1.6601	115.35	120.18
7	5	118.461	1.6601	116.04	120.88
8	5	117.941	1.6601	115.52	120.36
9	5	114.794	1.6601	112.38	117.21

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Vita

Captain Joseph A. Servidio graduated from Meadville High School in Meadville, Pennsylvania. He attended undergraduate studies at Edinboro University of Pennsylvania and enlisted in the Air Force in 1992. He spent nine years as a Medical Laboratory Craftsman at various assignments culminating at the 382d Training Squadron, Sheppard AFB, Texas. He completed his undergraduate studies at Midwestern State University, Wichita Falls, Texas where he graduated with a Bachelor of Applied Arts and Sciences degree in December 1999. He was commissioned through Officer Training School, Maxwell AFB, Alabama in 2001.

His first commissioned assignment was as a logistics plans and programs officer at the 354th Logistics Support Squadron, Eielson AFB, Alaska. In 2003, he was assigned to the 354th Logistics Readiness Squadron as commander of the Vehicle Management Flight. In April 2004, he was assigned to the 314th Logistics Readiness Squadron, Little Rock AFB, Arkansas, where he served as the commander of the Readiness and Aerial Operations Flights. While stationed at Little Rock, he deployed overseas in January 2006 to Diego Garcia, BIOT as commander of the Logistics Readiness Flight. In August 2006, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to the Air Force Logistics Management Agency.

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14. ABSTRACT
To sustain operational effectiveness, the Air Force has invested in the research and development of space-based technologies. Certain ongoing spacelift research efforts are focused on developing operationally responsive Reusable Military Launch Vehicles (RMLV) capable of launching payloads into orbit within hours of a tasking notification. Previous Air Force Research Laboratory-sponsored AFIT studies have resulted in the development of the MILEPOST discrete-event simulation model. This model has enabled the ability to analyze the impacts to responsiveness and manpower requirements given different RMLV design alternatives. The focus of this thesis is to improve the fidelity of the MILEPOST model by developing parametric models of simulation process times in terms of certain influential factors which affect maintenance task times.

Based on MILEPOST process modules, the research developed a Work Unit Code (WUC) structure, providing the means to document key maintenance tasks which are required during the regeneration of the vehicle. Additionally, the research determined that significant parametric relationships exist between task times and certain influential vehicle design and human factors. Incorporated into the MILEPOST model, the identified prediction expressions provide a more precise evaluation of RMLV design alternatives.

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